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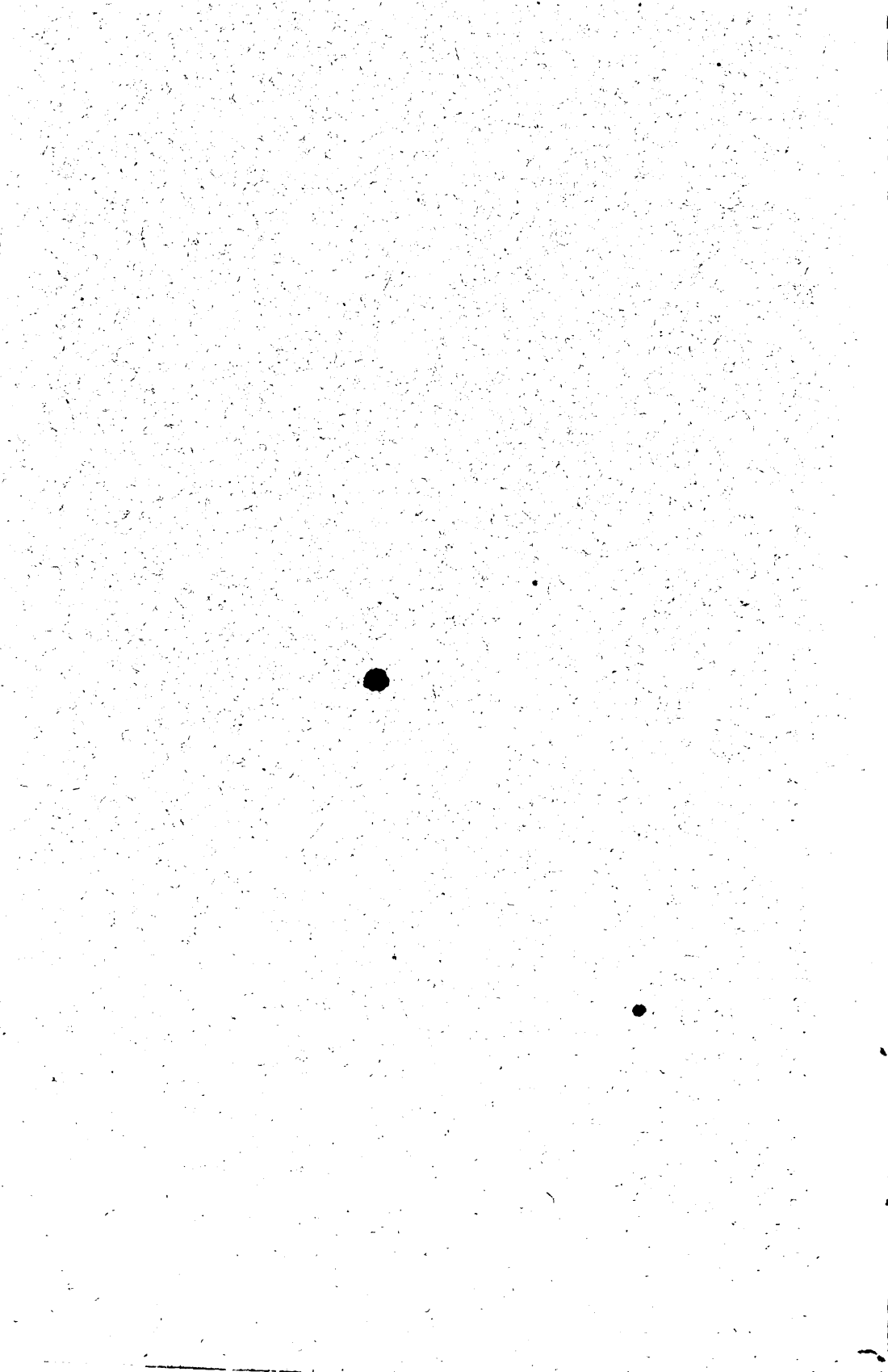
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A Deep Waterway from the Great Lakes to the Gulf of Mexico

PAPERS BEFORE THE WESTERN SOCIETY OF ENGINEERS

By

JAMES A. SEDDON—*Lower Mississippi River from the Gulf of Mexico to Cairo*
LYMAN E. GODLEY—*Cairo to the Sanitary and Ship Canal at Lockport*
ISHAM RANDOLPH—*The Sanitary and Ship Canal of Chicago*

Discussions by

LYMAN E. GODLEY	ISHAM RANDOLPH
ROBERT E. McMATH	THOMAS T. JOHNSTON
C. H. TUTTON	JAMES A. SEDDON

Introduction by
The Legislative Committee

The Illinois River Valley Association

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Compliments of
The Illinois River Valley Association
By
The Legislative Committee

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(B. R.)—The Legislative Committee does not assume responsibility for the opinions herein given, but recommends the resolution of the problem as the highest expression of the engineering profession.

The Lakes and Gulf Waterway

INTRODUCTION.

A waterway, sixteen hundred miles long, from Lake Michigan to the Gulf of Mexico, and nowhere less than twenty feet deep at all stages, is discussed in the following series of papers recently submitted to the Western Society of Engineers. Projects and estimates are given for the several sections of the route, by men who have spent the better part of their lives in especially qualifying themselves to treat the problems involved in such an undertaking.

That such a waterway can actually be produced, and at reasonable cost, is a question for primary consideration. However desirable it may be, general support cannot be enlisted until it is fully recognized that it can be done and that it will pay to do it.

The Legislative Committee of the Illinois River Valley Association, in the line of its duty to the residents of the Illinois Valley and the country at large, undertakes a wider circulation of this important series of papers for the benefit of those who have given little direct study to the problems, and are concerned in shaping public sentiment.

The committee urges all who have an interest in the subject to read these papers carefully, and in that connection to consider the present and future welfare of our valley, our state and our country.

The projects and estimates are briefly recapitulated in the following notes:

The Sanitary and Ship Canal of Chicago has been opened across the Chicago Divide for a distance of 28 miles, and at a cost to date of \$33,000,000. To complete this work to its full capacity of 10,000 cubic feet of water per second, and improve 6 miles of the Chicago river, will cost several millions additional. The full channel is 24 feet deep below low water of Lake Michigan, 160 feet wide in rock cutting, 202 feet wide on bottom and 300 feet wide at surface in earth cutting. The entire cost has been borne by the people of Chicago without aid by the state or federal government. The port of Chicago is only second to New York in the volume of its commerce and the need of improved harbor facilities is more urgent than at any other great port of the world.

From Lockport, the end of the Chicago canal, to the Mississippi river, the project and estimate are given by Mr. Cooley.

To extend canal depth over the eight miles from Lockport to Lake Joliet will cost \$8,000,000; thence to the head of the alluvial

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river at Utica, 54 miles, the fixed works are to be constructed for the ultimate depth and the intermediate channels dredged for a present depth of 14 feet, all at a cost of \$10,000,000. From Lockport to Utica, the project is for a plain slackwater improvement for a descent of some 140 feet.

Below Utica, for 227 miles to the Mississippi, is a simple problem of cutting, by means of hydraulic dredges, a deep channel which the flow of lake water will maintain. The full flow of the Chicago canal is adequate to a channel of 14 feet and the estimated cost is \$7,000,000.

Mr. Cooley calls special attention to the peculiar character of the lower Illinois river. With hardly a thirtieth of the natural low water volume of the Missouri or Upper Mississippi, it yet had nearly the same navigable depths at low water, and it is in this channel that more than ten times the natural low water volume is to be added. While the government, in other rivers, dredges low water channels that are obliterated by each succeeding high water, this deep channel will be maintained by the increased flow and without deterioration. This deep channel will also give better drainage to low lying bottom lands and mitigate overflow.

The waterway of 20 feet is a simple question of increased flow and further dredging. Mr. Cooley estimates that more than double the flow of the Chicago canal will be required, and puts the total cost of the additional depth from Lake Michigan to the Mississippi at \$60,000,000. This is a matter for the future and for progressive development, and by the time it is reached the increased flow of lake water down the valley may be very desirable.

Provisionally, Mr. Cooley proposes a dam in the vicinity of Alton to which the deep water of the Illinois may be carried and thence, if necessary, a short section of canal to St. Louis harbor. Until permanent works can be provided below St. Louis, the natural stage of water, supplemented by hydraulic dredging at low water, will provide 14 feet during a large part of each year.

With the larger flow of water the development of 20 feet from the mouth of the Illinois to St. Louis would be a work of progressive development similar to that for the Illinois river. Below St. Louis, Mr. Cooley considers that a dam in the bluff gorge at Commerce, some 50 miles above Cairo, high enough to take ~~out~~ about half the slope, will so modify the stream that with the larger volume of water a depth of 20 feet at low water can probably be worked out. He notes, however, that a deep waterway over the Middle Mississippi has not been fully studied and that further investigation may bring out a superior project.

A deep waterway over the 1,100 miles of the Lower Mississippi, from the Gulf of Mexico to the proposed dam at Commerce, is discussed by Mr. Seddon, and his project is a radical departure from the present plan of improvement. The Lower Mississippi valley consists of a series of great basins lying on alternate sides of the river, extending from 30 to 50 miles back and depressed from 10 to 30 feet below the high water banks. The natural river has always poured extreme flood waters into these basins to return to the river at the lower end and pour out again into the next basin below.

For the past fifteen years the several states and the general government have combined in building levees to shut out this overflow and reclaim the land. The end sought is most commendable, but the works so far developed make it clear that to completely shut out the overflow from these great basins will raise the level of extreme high water some six to eight feet. In view of these facts, Mr. Seddon considers that the increasing risk due to every extra foot of levee height against all the land along the whole valley, makes some less dangerous form of protection absolutely essential.

Mr. Seddon proposes a large reservoir system at the head of the valley, and to utilize the St. Francis basin for this purpose. He estimates that the capacity will be sufficient to cut extreme high water down to the bank level as far as the mouth of the Arkansas river, and that below this a very moderate system of levees will give immunity from overflow, and he contrasts this with an extreme flood held ten or twelve feet above the banks between some 1,500 miles of earth levees.

The sites for the reservoirs would be largely the unreclaimed lands in the back of the St. Francis basin. It is proposed to divide up this basin by a series of cross levees, so that flood water may be impounded by a series of moderate earth embankments, and the rupture of one of these banks would not entail any serious danger to life and property. This series of reservoirs is to be filled from the top of floods through controlling works near Cairo.

Mr. Seddon proposes to discharge these reservoirs from the lower end of the basin, near Helena, during the low water season, and considers that thereby not less than twenty feet of water will be produced and maintained at all times between Helena and the Gulf of Mexico. He proposes a system of slack water up through his reservoir system from Helena to Commerce, 50 miles above Cairo, there meeting the 20 foot project already outlined from Lake Michigan to Commerce. He is of the opinion that such a system will not be appreciably affected by sediment in a century.

The range between high and low water from Cairo to Helena will be materially reduced, and below Helena Mr. Seddon considers

it will rarely exceed 20 feet, in the place of a present range of some 50 feet. The banks are of light alluvium, now subject to destructive bank erosion, and this change in condition is expected to produce comparative stability. The present bank erosion is estimated to average 125 feet per year.

Mr. Seddon states that a conservative estimate for bank protection is \$80,000,000, with \$5,000,000 yearly for maintenance, and that this is now given up on account of cost, and that a permanent improvement of the low water channel is necessarily given up with it, as dykes can accomplish little in the absence of fixed banks.

For levees for flood protection, the states have spent some \$35,000,000 and the United States some \$15,000,000, and it is estimated that \$20,000,000 more will be needed to complete the system and \$2,000,000 yearly for maintenance. Mr. Seddon states that there are possible flood combinations from the White and Arkansas rivers that are beyond the capacity of the work projected.

Mr. Seddon states that the present plans for the improvement of the Lower Mississippi reduce practically to the completion of the levee system and to maintaining such low water depths as may be feasible by means of a large fleet of hydraulic dredges, which cut channels across the bars, to be obliterated by each succeeding high water. The forty millions which have been put into the river he regards as largely a tribute paid to experience: not that it has been wasted, for what could and what could not be done with such a river had to be tested once for all.

Mr. Seddon contrasts the expenditures and results with the alternative project proposed by him, at an estimated cost of \$32,000,000 for his reservoir system and complete flood protection, and \$12,000,000 additional for the extension of deep water navigation from Helena northward through the St. Francis basin. In round numbers, fifty millions may be taken as the total, to Commerce. Could the work have started out with the primary idea of regulating the flow a completed river improvement would now exist, for the river would have regulated itself. To hold the river directly against the destructive forces of flood volume, by means of dykes and revetments, is prohibited by cost.

The discussions of Messrs. Randolph, McMath, Johnston and Tutton practically express unqualified approval of the main propositions.

The foregoing projects are a radical departure from the projects which were considered sufficient a generation ago. The growth in knowledge and experience, the development in methods of construction and the increase in available resources, would all justify a recon-

sideration ; but the great development and change in transportation conditions has rendered these old projects obsolete, and makes a radical change imperative.

Those who have taken an active part in promoting our interior waterways have found, in many cases, that their hopes have not been realized. The water-borne commerce on some of these rivers is quite insignificant, while few water channels have held their place as carriers against the rapid growth and marked economy of railway traffic.

The reasons only need to be stated : Considering the fixed element of cost in freight movement (usually known as terminal cost or that factor which makes the short haul relatively more expensive than the long haul), products once upon the cars cannot be transhipped to boats and carried over the two or three hundred miles of a waterway for nothing. Again, the six to eight foot hulls of river traffic have not so marked an economy that they can draw railway freights for reshipment over much longer distances.

With the extension and consolidation of railway systems, river commerce is thus more restricted to the coasting trade of a narrow belt in which the products can be teamed for a few miles only for any difference in freight rates, and when the business has developed enough to pay, the trunk system has but to put out a feeder to take it.

In marked contrast with the decay of river commerce is the phenomenal growth of lake commerce. In large boats, over long distances, it brings the ore to the fuels, the raw material to the manufacturer, the timber to the builder ; and actually, the ton of coal is carried the thousand miles from Buffalo to Duluth for about the cost of shoveling it from the sidewalk into the cellar.

In this assembling of crude products, otherwise locked in, new industries are created, and on such routes great cities are now builded. Here the waterway and the railway each develop a special function and co-operate in a mutual advantage.

A waterway equal in every respect to present lake routes in its carrying capacity, and extending from Lake Michigan to the Gulf of Mexico, holds out such promise of commercial utility as the wildest imagination of today can scarcely realize. With such a waterway the products of the great interior would receive a large part of the difference between the long haul to the seacoast and the short haul to this interior seaboard. Here, also, born of the opportunity, industries not now dreamed of would spring up to enrich the enterprise and reward the labor of the great valley between the Rockies and the Alleghenies.

A waterway of a navigable depth of twenty feet at all seasons,

from the Great Lakes to the Gulf of Mexico, is shown to be feasible, by the group of professional men who are best qualified to judge. The cost is shown to be well within the resources that may be applied to it—in fact, to continue the present expenditure only, and on a well-digested plan, will bring it to pass. Such a waterway is absolutely essential to the development of the great interior. No other strip of territory on earth has the natural resources of that of the meridian of the Mississippi river on this continent.

The enterprise has been splendidly initiated by the city of Chicago. The state of Illinois for over ten years has declared public policy to be the production of a waterway of not less than fourteen feet, and this declaration has been adhered to in all the agitation of this matter. Such a waterway can now be produced from Chicago to St. Louis for less money than any other waterway of equal length and capacity, and is amply justified; and it is feasible, by the aid of hydraulic dredging, to carry this depth southward for a large part of each year. This development is immediately practicable.

Foresight only is required in the construction of a half dozen permanent locks to permit a progressive development to twenty feet, so it is not now necessary to contemplate the ultimate expenditure. No other waterway lends itself so admirably to a treatment by which large beneficial results are to be obtained progressively with the expenditure. It is not, therefore, necessary to consider the total estimate for the ultimate development, further than is involved in lock depth, as a condition precedent to undertaking the project.

The Lower Mississippi may be considered to stand on its own basis. The immediate and most potent motive in that territory is the reclamation and protection of the alluvial lands, and the efforts in this direction will not cease until the purpose is accomplished. The treatment herein proposed accomplishes this in the safest and most permanent manner, and within the limits of justifiable cost. The same treatment also produces the great waterway necessary to a fully developed route to the gulf, so both objects are conserved in the new project.

The objects to be accomplished are so great that they should enlist the serious attention of the continent.

THE LEGISLATIVE COMMITTEE.

RESERVOIRS AND THE CONTROL OF THE LOWER MISSISSIPPI.

Gulf of Mexico to Cairo.

BY JAMES A. SEDDON.

Read June 20, 1900.

Perhaps the first comprehensive idea of river improvement that suggests itself is always that of a reservoir system, though of course at the beginning more or less river work may be carried on without any comprehensive ideas whatever. Cutting a canal around a rapids to extend navigation into upper reaches; the protection of an eroding bank that is threatening to destroy the wharfage of a city, or dredging a channel through a bar that is a serious obstruction at low water,—are all simply immediate efforts to remove local evils; and even when these go further and the banks are protected and suitable dykes are built so that the low water bar will not again form in that place, it is still open to the question whether after all it is not much the same as what in medicine might be called treating symptoms—doctoring the pain but leaving untouched the real ill which caused it.

Whatever, then, may be said for or against proposed reservoir systems—and, as it will be seen, in cases, much may be said against them—they yet have the merit at least of raising the thought above the limits of simply local works, which may or may not be river improvements. The idea is a fundamental one that the ills of the river in the main lie in the variations of its flow—with a destructive flood at one season, and not enough water in it for navigation at another—and to equalize the flow is the first, if not the only, step required to making the best of the river.

While this primary idea is a very comprehensive one, and the longer the ills of rivers are studied, and the better they are understood, the more certainly are they traced finally to this cause, still it is at the same time a very simple one. To hold back the excessive volumes of the floods in reservoirs, to be returned to the river when it has reached its lower stages, probably strikes every one at first as an immediate and complete remedy. Popular science also has built up on the same foundations a number of plausible deduc-

tions, where the rivers are taken as becoming worse or better as nature is assumed to be working on these lines to a greater or less extreme in flood discharges. Cutting down forests, draining lands, reclaiming swamps, with all the climatic changes that are assumed to go with such development of a country, are each and all given a place in these deductions, and that some of them actually have a place in the flood regimens is possible; but what this is, and what its magnitude and, indeed, even whether in a given case it would increase or decrease the flood extremes, is in general beyond the range of our present knowledge of the subject.

Thus taking the simplest case, that of a complete drainage system covering a large agricultural area: there is no question but that its action is to run off the rainfall more rapidly than it would pass into the river in a state of nature; but whether this would increase the flood extremes there or not would probably depend upon whether it ran out before the crest of the flood from above reached that locality, for if, in general, the flood from above arrived later, the retardations of the natural drainage system would be the condition that would tend to combine to give the greatest flood extremes there.

With the action of the forests on the run-off still a matter of speculation; little really known of the different effects as between the farm land and the prairie; many of the popular impressions in regard to climatic changes not as yet borne out by our meteorological observations, and even the simple case of tile drainage, while known in its action as yet unknown in its combinations with all the other contributions to the river, it is plain that this is no field for such general deductions. The questions in it are special questions of fact, and while the data can certainly be taken to settle all of them in general they have not yet been taken to settle any of them.

The effect of reservoirs on a river system is in much the same way simply a question of fact. Where located at the head waters there is the same uncertainty whether the water stored in them is that which would combine to make the destructive flood below. And where the flood below is a combination of several rivers, as it is in all the main waterways of our intercontinental drainage system, the question practically gets beyond the theorist. Each case is to be settled only in a special study of its data, and that only in so far as the data have been taken to determine it.

It is true, however, that, unlike the natural influences before noted, the reservoirs are under intelligent control. They may come in time to be operated so as to withdraw the flood waters at such periods as experience shows on the whole will produce the best results; and they may be very generally run out on the low

waters about when they are most needed. And while certainly their contributions to the low waters may not amount to much, where long low water periods are the ordinary conditions of the rivers, still such contributions are never really lost and their good effects may very possibly have been so far underrated.

For both of these reasons, in estimating the effects of reservoirs this question of efficiency that lies in their operation may for the time be omitted. Laying aside the doubts noted of how their withdrawal of a flood excess at one point will fit the combinations that make the flood below, it may be assumed anywhere that they take off from the top of the flood as much as they will hold, and their flood effects estimated on this basis—remembering that this is a limit that can never be altogether reached in any case, and may be very far from being reached where the reservoirs are located on the river a long way above the point where the flood is considered.

Then with this basis, for a system of reservoirs to prevent the overflow in any of the extreme floods of a river, or to reduce the flood to the level of the ordinary bank-full stage, they must be large enough to hold all the water that passes in the period of overflow, in excess of that which would pass in the same period with the river within the banks. Or, again, if a greater reduction was considered, say to two feet below the bank level, the flood excess which the reservoirs must hold is that which passes less than which would pass in the period with the river this two feet lower. This flood excess is a matter of the duration of the flood, or the number of days that it is above this assumed level, and the discharge capacity of the river for all the stages that it goes through on its rise and fall between this level and the top of the flood.

Again, the effect of a return of this to the low water period is the higher level that is maintained through the low water by the greater flow that this return gives it; and depends in the same way upon the duration of the low water and the discharge capacity of the river through these lower stages. Both of these effects, however, may be very closely estimated in any case where the discharge of the river for all these different stages has been well determined, each being the summation of given differences in discharge from day to day through the period, which as a whole is to make a volume of water equal to the capacity of the reservoirs.

But while such methods of calculating the effects of given reservoirs at any point of the river are simple enough (and any one may certainly go over the ground in this way from point to point along the river for different assumed reservoir systems, and for the different floods that follow each other from season to season, so as to fully cover the matter, and reach, finally, general conclusions that

he can count on as altogether safe) still it is not easy in the first place for him to so cover the matter as to fairly judge the subject; and, in the second place, after he has done so it is then almost as difficult for any one else to decide whether he has judged it correctly.

It is only in the method of directly showing all this matter that the question of reservoir effects becomes a comparatively simple one; not only for the engineer to form a correct judgment of it, but for anyone who cares to follow him to see that he has done so. It has long been the practice to show the flood regimen of a river by platting in succession the hydrographs from the head waters down. This hydrograph of the river, at any location where a gauge record has been kept, is made by taking a horizontal distance to represent the year and dividing it into the corresponding months and days, at each of which the gauge reading, or the level of the water in the river on that day, is plotted to a suitable vertical scale. The line joining these points, then, from day to day gives the hydrograph, which shows for that location in sequence all the rises and falls of the river through flood and low water periods of that year.

Taking one horizontal scale for the given year on which the hydrographs of the given gauges are plotted in order down, the whole flood regimen of the river is brought under the eye at once, and shows the magnitude of all rises and falls in the order of their occurrence. It does not, however, as yet show anything of that essential element in the reservoir question—the discharges of the river at all these different stages. For, of course, a rise of 25 or 30 feet is a very different thing in a river a hundred feet wide and in one a thousand feet wide; in the first, a given reservoir system may have the capacity to take off half the height of its average floods, while in the second its effects might be hardly appreciable.

To meet this requirement the showing of the discharge scales must be combined with these hydrographs. This discharge scale, at any point of the river, simply marks the levels from low water up for uniform differences in discharge just as the gauge scale is marked for uniform differences of level. This river discharge is generally given in thousands of cubic feet per second, the thousand cubic feet per second being taken as the unit in which the flow of these great waterways is reckoned. Taking, then, 50 thousand cubic feet a second as the uniform difference to be marked on the discharge scale, the first level above low water would be that of this 50 discharge; and this level drawn through the hydrograph would show at just what points in the year the river's flow had reached this discharge, with what periods and by how much it was above or below it, everywhere through the rest of the season.

MAP OF THE MISSISSIPPI DRAINAGE SYSTEM

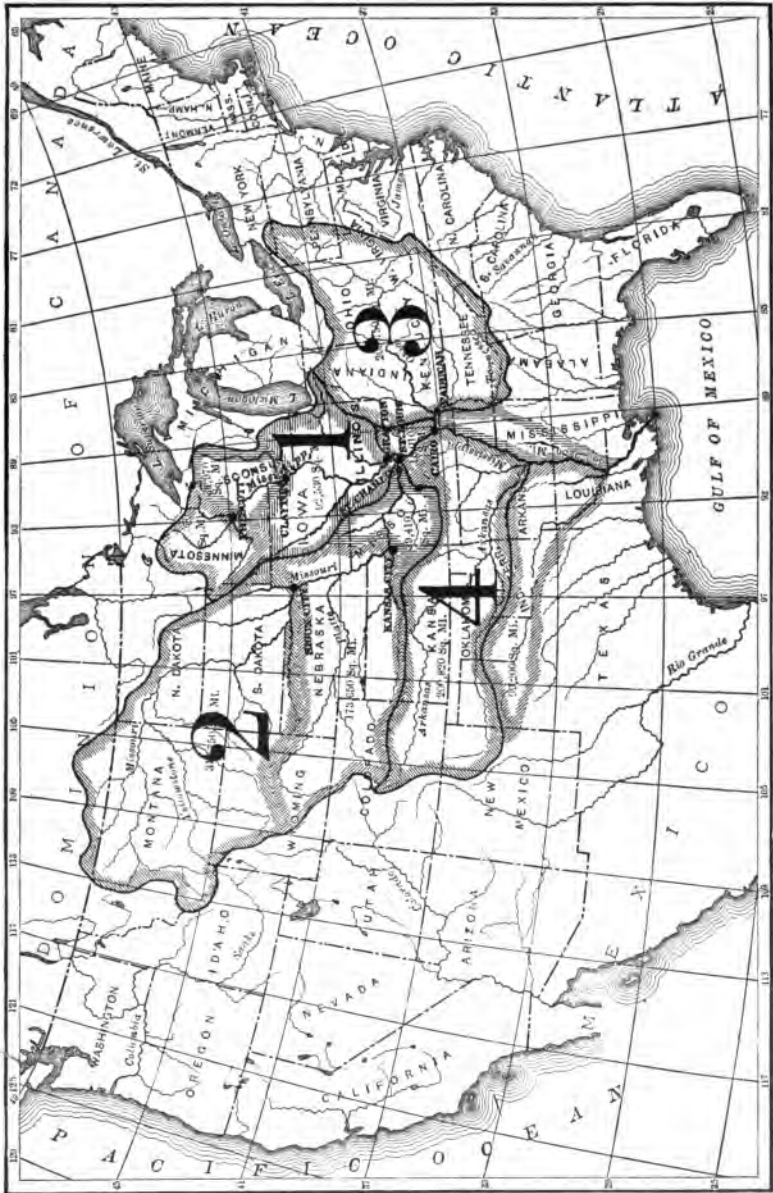
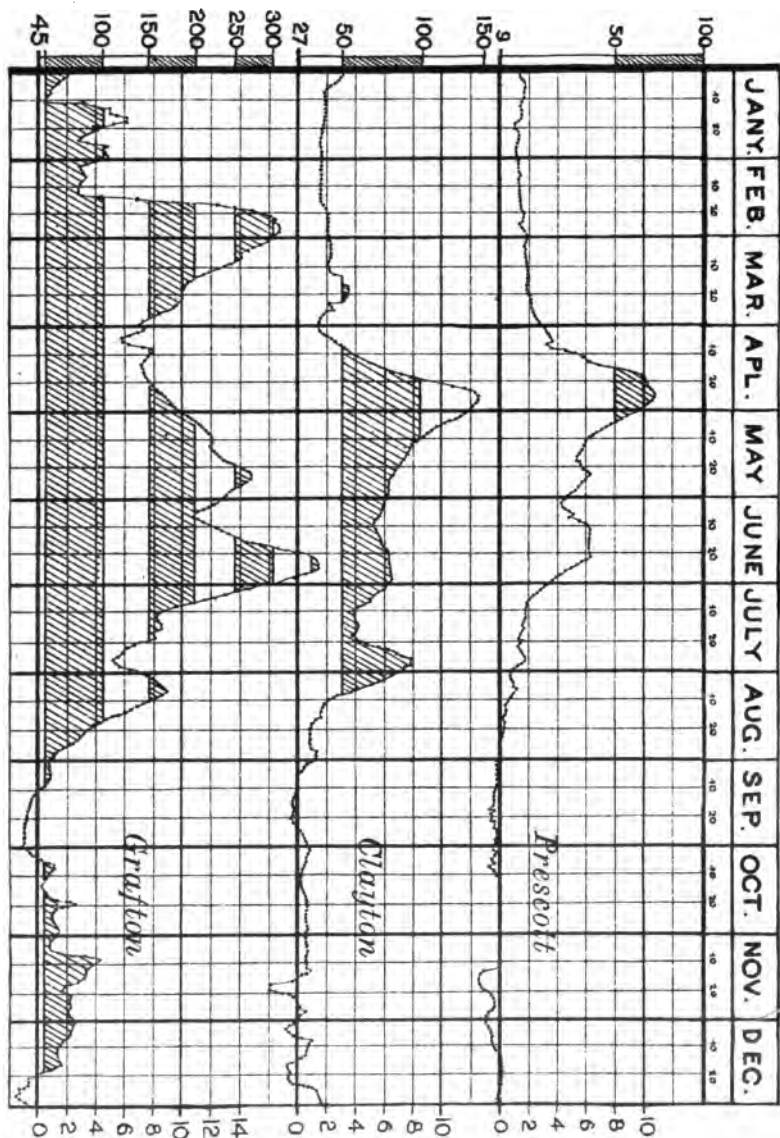


Fig. I.

Discharge in 1000 Cub. ft. secs.



Stage in feet.

Fig. II.

The second of these 50 intervals on the scale marks the level of the 100 discharge in the river, and, drawn also through the hydrograph, shows immediately all the periods in which its flow is between this 50 and 100 value, while in general this interval on the scale is close enough for the discharge of any day in these periods to be read on this showing directly with sufficient accuracy. Continuing, then, this process from the low water up to the extreme flood level, and shading the alternate scale intervals for the convenience of reading the discharges through the hydrograph, the whole thing finally shows immediately, not only the sequence of stage through the year but also everywhere the discharge or the flow of the river that corresponds to it.

With this preliminary outline given, drainage systems and their combinations may now be considered. And, indeed, it is only in carrying these questions into the data of actual rivers that the problems can be fairly seen and the methods of determining them appreciated. The map, Figure I, gives the whole drainage system of the Mississippi, and on it the divisions that will be considered in succession are shown as 1, 2, 3 and 4, respectively.

Upper Mississippi System.

Division 1, Figure I, covers the Mississippi river from its head waters to its juncture with the Missouri, and is also here subdivided into the upper, middle and lower basins, the upper ending a little below St. Paul, at the juncture of the Mississippi river with the St. Croix and including the flow of that river. The middle basin covers the drainage from there down to below the mouth of the Wisconsin river, while the lower extends to Grafton and includes the Illinois river, the last of the tributaries above the Missouri. These subdivisions are taken to correspond with the series of discharge observations made by the Mississippi River Commission through the flood season of 1880-81, and known respectively as the Prescott, Clayton and Grafton series, and it is from these data that the discharge scales are determined which are taken in the showing of the Upper Mississippi flood regimen given on Figure II.

On this, as seen, the hydrographs of 1883 have been platted in order down for Prescott, Clayton and Grafton, at each point showing the water level of the river from day to day with all its sequence of changes through the season. The heavy lines at the bottom of the hydrographs are taken respectively at the levels of the ordinary low waters, and from this line as a zero the stage is marked at intervals of two feet by the horizontal lines above it, while the vertical lines mark the months and intermediate ten day periods.

The discharge scale begins at the discharge of this ordinary low water level, and above this the 50 level, the 100 level and the 150,

and so on are marked in succession. The 50 level is drawn through the hydrograph for all the periods in which the stage of the water is above it; the same is done with the 100 level, and the area lying between these two levels in each hydrograph is shaded. This marks distinctly the limits and the periods of this flow from point to point down the river, while in contrast the belt between the 100 and the 150 level is left blank, and again that from 150 to 200 is shaded. The top lines of each shaded area thus mark the alternate 100 discharge levels in succession and the bottom the alternate 50 levels.

With this it is in general easy to estimate the discharge quite closely at any one of these locations on the river, and at any period of the year. Thus, at Prescott the top of the April flood is something less than half the level between the 50 and the 100, and is not more than a 75 discharge at its highest, while at the same time the crest of the Clayton flood comes very nearly to the 150 value. But though the discharge of this flood at Clayton is about twice as large as it is at Prescott it is still very plainly the same flood, only swelled by the contributions of the tributaries between these points to double its flow by the time it reaches Clayton. But between Clayton and Grafton it is equally plain that its character as a distinct flood is wholly obliterated.

True, all the water that passes in the river at Clayton must be found after an interval passing in the river at Grafton; but in this case the contributions to the river from the lower drainage basin make the main flood at Grafton, and come in to give a high water there at a wholly different period. As a fact, however, the crest of this flood from Clayton is here indicated in the stand at Grafton about May 10 with discharge of 220; which makes a lower contribution of 70 to the 150 discharge from Clayton. But even with this contribution it is still but little more than a medium stage at Grafton, while the main floods of the year occur there about the end of February and the end of June, or some 70 days earlier and 45 days later, with discharges of 300 and 350 respectively.

In all this, however, it is not necessary actually to read off the discharge values to reach such conclusions; the whole thing strikes the eye at once in the first glance at it. Bearing in mind the fact that the height of these intervals of alternate shading within the hydrographs represent everywhere equal discharges, and that their breadth or extension on the time scale is the period that they hold in the river; they simply give a correct view, in true proportions, of all the flood volumes and their sources. Thus, the small fraction at Prescott of the shaded area above the 50 discharge level is placed, as a whole, in contrast with the much larger showing at Clayton below it; and the relative magnitudes of the two floods with the

Clayton excesses are everywhere just as distinct as the areas of a square foot and a square yard placed side by side would be.

In this way it is seen directly that all the flood waters to the end of March at Grafton come in from entirely below Clayton, this upper river being but little more than an ordinary low water stage; or less than 50 of the 300 extreme discharge which the flow at Grafton reaches at the end of February. Through April again the whole river is rising, together with the large contributions, however, from basin to basin before noted. Following this the decreasing flow from above is more than balanced by the increasing contributions from the lower basin, which reaches the extreme of some 250 discharge near the end of May, while again at the end of June the Grafton flow reaches 350, of which only about 80 comes from Clayton. And, finally, early in August there is a small rise shown that has its origin very clearly between Prescott and Clayton and marks about a ten day interval for the flood movement from there to Grafton.

This direct showing of the volumes of the floods from point to point down the river, in the first place, makes it clear where reservoirs would have effects. Thus it is plain that no reservoir systems above Clayton would have had any effect on the flood extremes at Grafton. The February flood, as before noted, comes in wholly from below and in the case of the June rise at Grafton, there would be no storage room left in the upper reservoirs had they been filled early in the season from the floods in their own localities; while, even if they had been kept empty for this contingency, it is very doubtful whether they could have reduced the flow from above just in the proper period.

In the second place, this showing also makes it simple and easy to estimate the specific effects of given reservoirs, or the dimensions of a reservoir system required to produce given effects. The unit of discharge, or the thousand cubic feet per second, is 86.4 millions of cubic feet in one day, or enough water to cover the surface of a square mile 3.1 feet deep. Taking, then, the reservoir surface in square miles and the depth to which it may be filled in feet, and expressing its capacity in the product of these two, or "square mile feet," the equality between any part of these floods and such a given reservoir capacity is quickly estimated. Thus the flood at Prescott above the 50 level is approximately a 20 discharge for 12 days and is therefore $3.1 \times 20 \times 12 = 744$ square mile feet—a reservoir area of 74.4 square miles if the average depth to which it could be filled was 10 feet; or, if filled to 20 feet depth, the half of it, or 37.2 square miles.

In this case it is also seen that such a system of reservoirs would cut down the level of the flood at Prescott some 2.6 feet, but when

run out again on the long low water of about 150 days following it, they would only contribute an average discharge of $\frac{744}{3.1 \times 150} = 1.6$ to the low water period. This would raise the river but little more than three-tenths of a foot through the low water period; and it is in such cases that a reservoir system may have quite a marked effect on the flood stages with little to speak of on the low waters that follow them. But it is easy to see that the case might be quite different at Grafton where a reservoir system that would materially reduce the floods of this season might be used to raise the extreme low water stages by several feet.

This will serve as an outline for the Upper Mississippi. Of course a full study includes the consideration of a number of flood years and a showing of their volumes at a number of intermediate locations, but what has been given is enough to bring out the general features of this drainage system, which is specially interesting in view of the fact that one of the largest reservoir systems of the world has been constructed above Prescott on the head waters of the Mississippi.

In the series of lakes that lie at these head waters, a great reservoir capacity is cheaply gotten; and, as a fact, the reservoir system constructed there can rarely be much more than half filled. But whether they could be filled or not, it is well to see that even at Prescott the low water of the river could never be raised to any great extent by them, while probably these effects would hardly ever be seen in the stages below Clayton. Above the St. Croix and the Minnesota rivers, of course, the low water effects would be some two or three times as great and might show a distinct improvement to the navigable depths there; while their effects on the flood stages of this extreme upper river is doubtless considerable.

The effects of these Upper Mississippi reservoirs, however, hardly touch the field of this study. The whole basin above Prescott gives but a small part of the final flood from this river, and the fraction of that which is under the control of these reservoirs must be left for more detailed studies. They probably have some effect on the extreme flood stages as far down as Clayton, and on the low water navigation above St. Paul, and very certainly furnish a substantial addition to the water powers of Minneapolis; but so far as any practical effect on the river at Grafton is concerned they might as well be located in the desert of Sahara.

Missouri River System.

The Division 2, Figure I, gives the drainage system of the Missouri, which is also subdivided into the upper, middle and lower basins. As, however, in this case Sioux City is as far up as the requisite discharges have been taken, the upper basin here gives a

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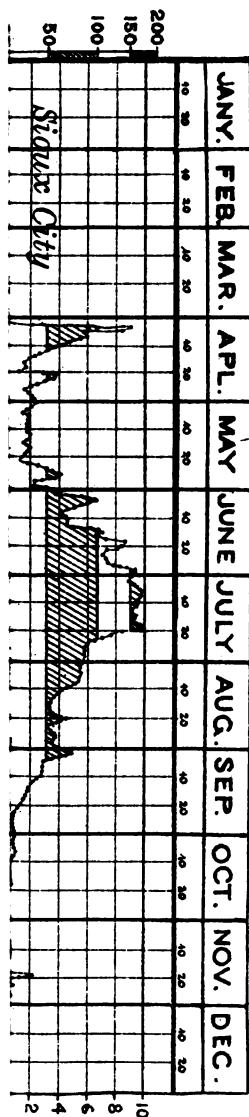
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FLOOD REGIMEN OF THE MISSOURI

1880



flood made up of more combinations and much further from the head waters than that of the like case on the Upper Mississippi. The two studies, however, cover about equal reaches, and, as it is more or less definitely known that the Missouri is much the same river for some five or six hundred miles above Sioux City, the marked difference in the character of its flood regimen over such a distance is a matter to be specially noted.

This is seen at once in the showing of its flood regimen on Figure III. There, for the year 1880, the hydrographs are given, in order down, for Sioux City, Kansas City and St. Charles, while from the level of the ordinary low waters at each point the discharge scales are marked and the alternate intervals shaded through the period as in the case of the Upper Mississippi. But unlike the case of that river, the volume of the main flood here shows little or no increase along its whole course. Thus the top of the July flood averages about 160 discharge at Sioux City and hardly more than 180 at St. Charles, some 800 miles below; while nearly all this 20 difference shows between Sioux City and Kansas City, and is probably also snow water from the head waters of the Platte river.

Head water reservoirs in the upper basins of the Missouri may thus be expected to have a much more marked effect on the floods along the whole course of the river than they could possibly have on such a stream as the Upper Mississippi. And as all this waste water is also badly needed in the arid regions for purposes of irrigation, they have certainly equal, if not better, claims on the government for their construction.

In the long low water periods their effects at best on that stage would not be material, and their service simply in the demands of irrigation would not conflict with any practical results that might be aimed at in the return of their stored waters to the river. However, 1880 is quite a low flood season that was selected simply to mark this contrast between the Missouri and Upper Mississippi most distinctly.

For the extreme flood regimens of the Missouri, Figure IV is given, which shows two of its greatest floods, differing most essentially in their character. Thus, the 1883 flood is below the ordinary high water at Sioux City, with discharge something under 150, but it receives a large addition to its volume from the second basin, reaching an extreme at Kansas City of over 400, which is again increased by the contributions from the lower basin to a discharge of something more than 550 on its crest at St. Charles. On the other hand, the crest of the great flood of 1881 is distinctly over the 500 discharge level from Sioux City to Kansas City, while actually something under this at St. Charles; and thus absolutely its whole

flow comes simply from head water contributions altogether above Sioux City.

The effect of head water reservoirs on the flood of 1883 of course corresponds more nearly to the case of the Upper Mississippi. In the basin lying between Sioux City and Kansas City, and covering mainly the Platte and the Kaw river drainage, reservoir systems could probably be filled directly with water that would otherwise go to swell the flood crest in the main river, but in the Sioux City basin they would have to be so operated as to reduce as far as possible the flow from above just in this lower crest period, and how far this could be done so as to reduce the extreme stage in the lower river, is one of those questions of intelligent operation that is a matter of trial and experience.

On the other hand, the flood of 1881 has no such questions in sight. It is known, however, that a large part of this main flood came from below the Yellowstone, and the distribution of the reservoirs in this upper basin, to have taken off its excess directly, is still to be settled. But assuming that the reservoir system there was located to do this, there is no further question for the rest of the river; to cut off the crest at Sioux City is to cut it off all the way down.

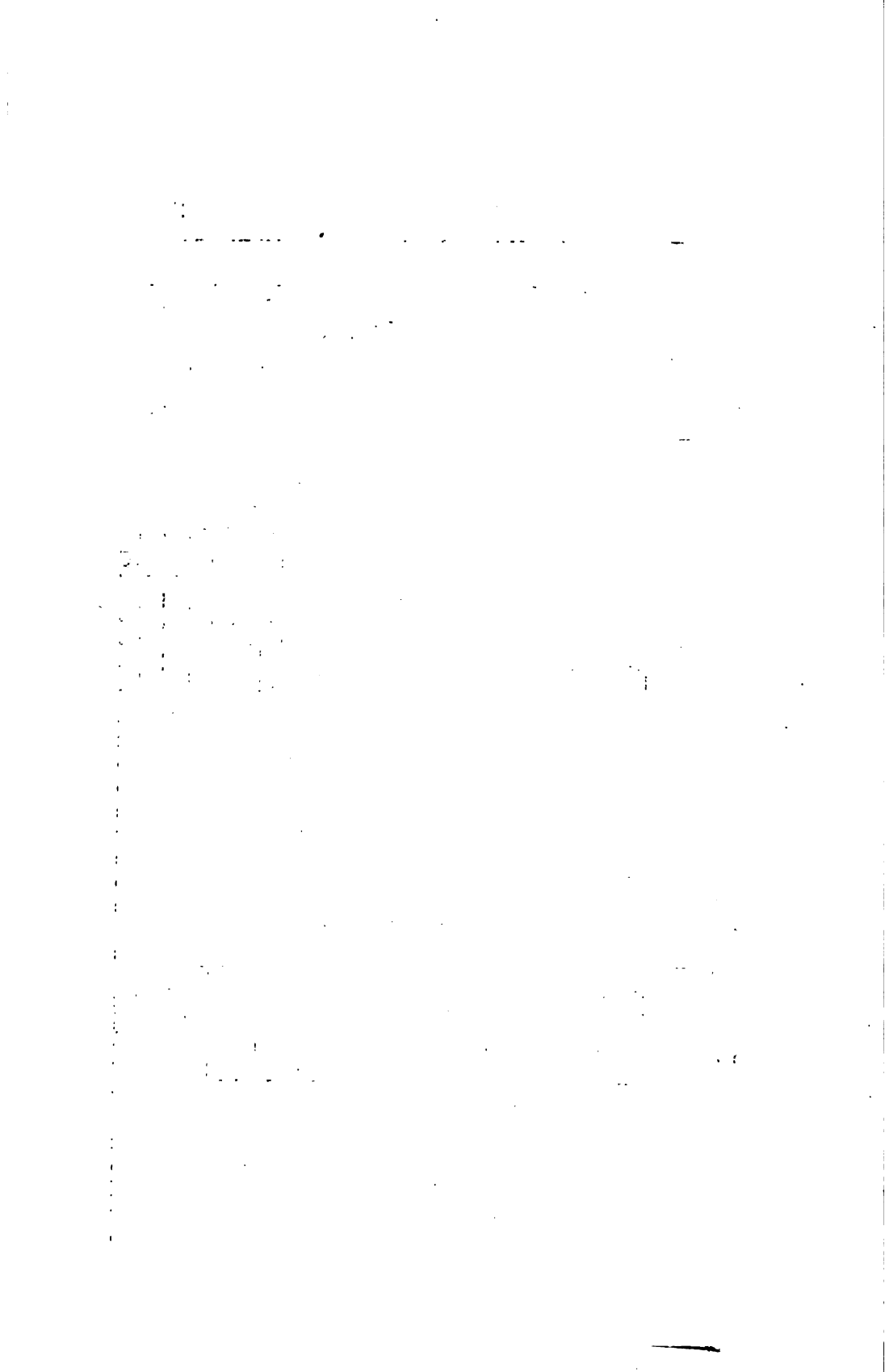
For an estimate of this, taking it in round numbers, between the 400 discharge level to the crest, the volume is about 100 discharge for 6 days, and between the 300 and the 400 level it is about 100 discharge for 10 days. Altogether, then, the flow above the 300 discharge level was: $3.1 \times 100 \times 16 = 4960$ square mile feet; or, say, it would take 248 square miles of reservoir surface 20 feet deep to hold it. This would have lowered the flood stage on an average some 5 feet along the whole river, and probably have rendered comparatively harmless the most destructive flood that has occurred since records have been kept on the Missouri.

It should be noted here, however, that such estimates are only approximate values, and especially so for the upper part of the Missouri, where no actual discharge observations have yet been made at any such extreme high waters, and the discharge scales are simply carried up to these levels with rates given by the observations at lower stages. But even where the levels are actually given by observed discharges in such rivers as the Missouri, it is equally well determined that from time to time they may differ materially.

There are a number of elements that contribute to this variation in the level of a given discharge. For instance, such a river may cut across a bend, altering its whole course and greatly reducing its length in that vicinity, with the level of a given discharge permanently changed there. And, indeed, after such a change, no discharge scale should be used for that location until a correct one

Discharge in 1000 Cub. ft. secs.

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could be re-determined for it. But, even where there are no such apparent changes in the character of the river, it is found that the level of the discharge scale is at best but a mean between limited rises and falls of the actual level of the given discharge from flood to flood and from season to season.

These variations in the discharge level run through periods, and change from above to below the given mean and back again, from causes that are as yet only partly understood; but as a fact in each they are in general very fairly covered by simply shifting the mean discharge scale as a whole up or down, as the case may be, from a tenth or so to the better part of a foot in any one of the periods. This is instanced on Figure IV, in the 1881 flood regimen of the Missouri. Through the whole time there, from the end of May to the end of September, the scales given show a larger discharge throughout at Kansas City than that passing St. Charles in the same period.

Such differences for a few days may be caused by ice gorges in the spring break-up, and they are also possible on the sharp crests of extreme high waters that flood the whole valley; but in ordinary conditions and through extended periods all the flow past Kansas City must show past St. Charles, with such additions as may come in from the tributaries between them; and the difference here given simply makes it plain that either the Kansas City mean scale is too low and its discharge showing too large, or, what is more probably the fact, that the given St. Charles scale is too high, and its discharge showing too small for the period. Thus, if the St. Charles discharge scale was put down altogether to about eight-tenths of a foot lower level, it would show through the whole period a fair degree of consistency in the amount of water passing from Kansas City to St. Charles.

On account of this apparent shifting, as a whole from time to time, of all the flow levels of the river at the given locality, this phenomenon of variation in the discharge levels has been given the general title of "change of plane," and in what follows will be so referred to. Thus, the mean discharge scales represent normal planes while the case of 1881 on the Missouri, just cited, is a plane lowered 0.8 foot at St. Charles from May to September; and in alluvial rivers it should be distinctly understood that the normal plane is simply a general equilibrium around which the varying levels of the different floods and seasons oscillate.

It is coming at the same time to be understood as well that the alluvial river in its form and dimensions is also simply an equilibrium between the erosive and bar building forces that its flow and its variations of flow give it. The erosion is well marked and fairly estimated by the average amount of bank that caves in annually;

and this, on the Missouri between Kansas City and St. Charles, is a width of over 70 feet a year along the whole length of that river. This, dumped into the deepest part annually, is an amount that would fill it up solid to some 12 feet above low water in the 20 years the government has been working on it, were it not for the fact that it is cleared out annually by the bar building forces of the flood period.

In the play of such forces, with their extremes of action not at all coincident in the yearly cycle, it is not surprising then that the discharge levels are from time to time shifted; and in more detailed studies, following the flood from gauge to gauge along the river, many of these changes of plane may be detected. But for taking the flood volumes on an average, from year to year, and from point to point along the river, these normal discharge scales answer the purpose. And, indeed, it is only as they do this that they are correctly determined.

Middle Mississippi and Ohio Combinations.

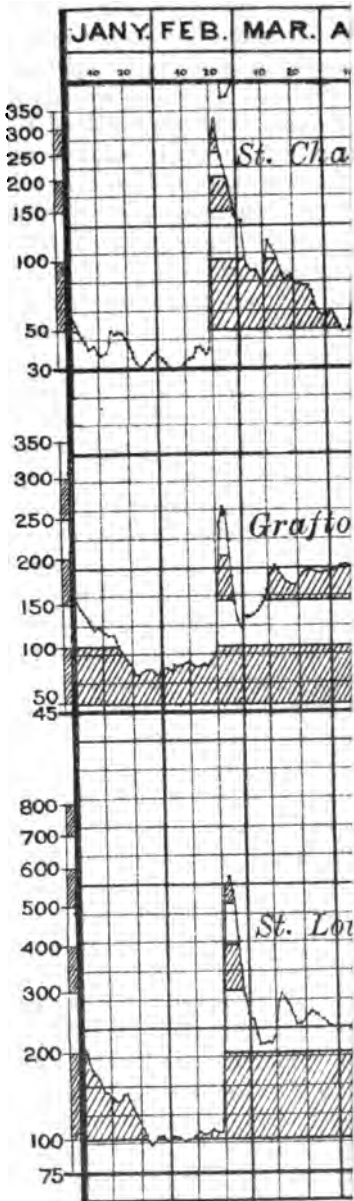
Aside from actual discharge observations, however, it is really in the combinations of rivers that these average or normal discharge scales are best tested. Taking, for instance, the Missouri at St. Charles and the Upper Mississippi at Grafton, their combined flow is necessarily just that of the Middle Mississippi at St. Louis. The summation of their scale discharges at any time will then give the St. Louis showing if it has the same plane; if, however, there is a different plane at any of these points, its difference will be marked by the discrepancy in this comparison.

Following this matter through a number of years in this way, here and there quite marked changes of plane may be detected. But, on the whole, the general agreement of the St. Charles and Grafton floods with their summation in the St. Louis flood regimen is really quite striking. For illustration, Figure V shows this combination for the year 1882.

The St. Charles and Grafton scales mark this difference in discharge as given on former plates, but for the showing at St. Louis a 100 difference for the marking of its scale is taken. The heavy line of ordinary low water at St. Louis, on which its discharge scale begins, is of course the sum of the low water flow from St. Charles and Grafton, and from there up its scale marks the levels of this doubled difference in the discharge, to correspond with this natural summation in the rivers. Thus, the top of the first shaded area at St. Louis is a 200 discharge, and corresponds to the top of the first shaded area at both St. Charles and Grafton, or the level of a 100 discharge from each of them, and so on up for the higher discharges.

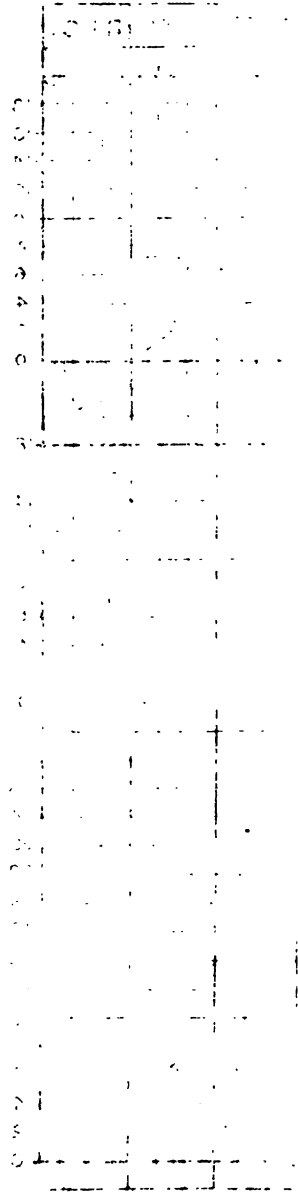
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With this, the flood year is quickly checked over. Thus in the low water the last of January, the showing of St. Charles and Grafton is somewhat large for St. Louis; or St. Charles about 30 and Grafton about 80, while St. Louis shows but a shade over the 100. This however, is in the period when the rivers are generally frozen over and during which the discharge scales can not be counted on. But on the break-up following it, February 20, the agreement is very close; St. Charles at the crest showing 300 and Grafton 250, with St. Louis crest just the sum of these, or 550. Through March, St. Charles falls and Grafton rises, holding an average of about 250, which, April 8, shows 50 from St. Charles, with a little less than 200 from Grafton, making about the 240 given at St. Louis. Next the crest of May 1 is, St. Charles 140, and Grafton 290, giving the sum of 430 shown on the St. Louis crest; and again the crest early in July of 350+ at St. Charles and 350+ at Grafton, makes the something over 700 at St. Louis. From this on there is a general fall till early in October, when the rivers all reach the ordinary low water level together, or a 30 St. Charles and 45 Grafton discharge, giving the 75 ordinary low water discharge of the Middle Mississippi. And, finally, rising with an average of 35 and 75 through November, they give the 110 average of St. Louis; after which the rivers freeze over and the irregular showings of the ice period begin.

Now considering the volumes of flow dealt with through this whole season, the possible discrepancy in these summations really shows an extreme small percentage of error in the use of these normal discharge scales. It, however, should be here noted that it does not follow that they give the actual values of discharge from day to day with the same precision. In the matter of changes of plane, for the lower rivers at least, a larger discharge on the front of the flood and a less on the fall is a common phenomenon; while at any time actual discharges say in excess, 20 at St. Charles, 20 at Grafton and 40 at St. Louis, would show no discrepancies on these scale values.

So far as this coincident change of plane is common to the three rivers, larger discharges on the rise and less on the fall may occur without showing any contradictions in these flood summations. And as also the rises and falls at St. Louis are the products of rises and falls at St. Charles and Grafton, some coincidence in changes of plane of this character may be expected. But in the volume of flow represented by the shaded area between any two of these discharge levels, the river has as much rise as it has fall in it; and for that, at least, these discharge scales should give the total flow in true proportions, in so far as they agree in these summations.

With what has been given it is, of course, plain that any effects of head water reservoirs on the flood stage of the Middle Mississippi depend solely upon whether the crest of the St. Louis flood coincides with the flood from the Missouri; for it has been seen that reservoirs at the head waters of the Mississippi have no effects whatever on the flood stages at Grafton. This coincidence in the St. Charles and St. Louis flood crests shows in this year on Figure V; and, indeed, this is very generally the case in the extreme floods of the Middle Mississippi; so that whatever reservoir effects can be brought down the Missouri to St. Charles come at the right time to reduce the floods at St. Louis.

But it will be noted as well, that the flood at St. Louis is that of a doubled river, and the reservoir water withdrawn from the Missouri crest will not show a like reduction in stage when taken from the top of the flood in the Middle Mississippi. This is not a matter of close estimates, as it depends more or less on the combinations, but approximately it may be said that reservoirs on the Missouri that would in general reduce the flood stages at St. Charles some five feet could hardly be counted on for more than a three foot reduction in the flood stages at St. Louis.

However, any reservoir effects that may be brought down to the Middle Mississippi again entirely disappear when it comes to the combination of that river with the Ohio. The total drainage system that contributes to this great flood of the Lower Mississippi is seen on Figure I, and the combination of the Middle Mississippi and Ohio rivers that make up its flood regimen for 1882 and 1884 respectively, are given on Figure VI.

Here the Middle Mississippi is given as before by the flood regimen at St. Louis, and the total flow from the Ohio basin (Division 3, Figure I) by the flood regimen at Paducah, 45 miles above its mouth, data for its subdivisions not as yet having been taken. On each of these the scales mark from low water up the levels of 100 discharge intervals, while their combined flow, shown in the Cairo stage close to their junction, is marked as before with the doubled scale interval, and corresponds to the sum of the equal 100 levels from the Middle Mississippi and Ohio. Thus the top of the first shaded area is a 200 discharge at St. Louis, 200 at Paducah, and the sum of the two, or 400, at Cairo, and so on for the higher levels.

In these combinations it is seen at once that the flood in the Lower Mississippi comes mainly from the Ohio river. True, in 1882 a short rise from above happened to coincide with the crest from the Ohio and adds something to the extreme stage at Cairo; but the total contribution of flood water from the Middle Mississippi is even in this case relatively insignificant, while in 1884 about the

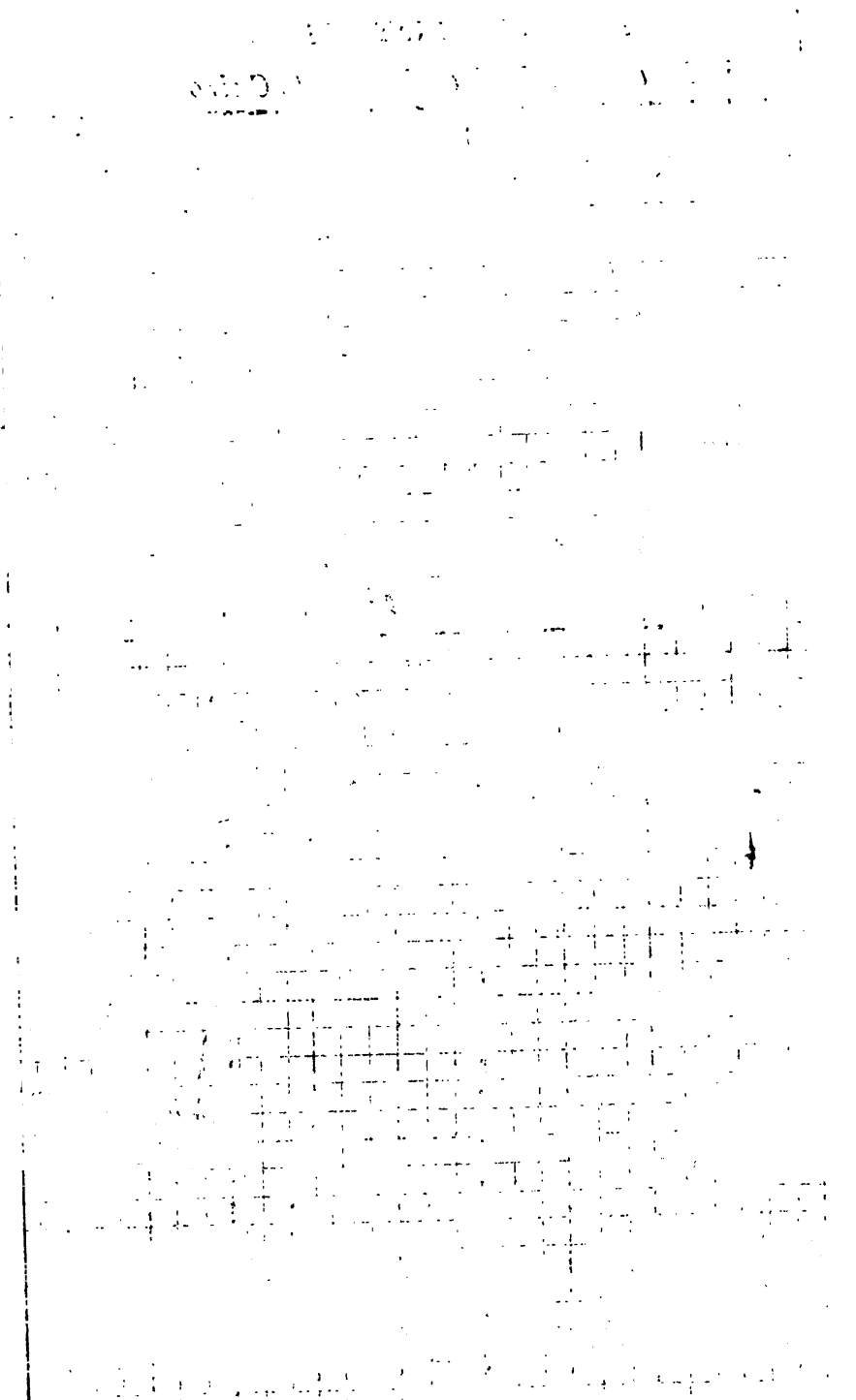
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same extreme is reached at Cairo with St. Louis at little more than an ordinary low water stage. Any head water reservoirs, therefore, that would affect this extreme must be located in the Ohio river basin and draw off the flood waters of that river.

This main flood from the Ohio may be looked for at Cairo about the end of February, while the spring rise of the Missouri in general comes in April, and the regular June rise some two months later and, combined with the Grafton flow, forms the flood at St. Louis. With this wide interval, then, of some two to four months between the high water periods, and the much smaller volume of the St. Louis flood, even the extreme high waters there have but little chance to affect the flood stages at Cairo, and however great the reservoir control of these upper rivers might be, and however large their flood reductions, about the same extreme floods in the Lower Mississippi would still come, as they have always come, from the Ohio.

Reservoirs in the Ohio river basin have long been proposed for the control of these high waters, and again such control from time to time has been reported impossible. But it may be here noted that the data have not yet been taken to determine in any definite way just what effects such systems of reservoirs might have on the final flood of that river. From the cases given for the Upper Mississippi and Missouri it is plain that to settle such questions the flood volume must be traced back to its sources, and beyond the 1882 series of discharges at Paducah practically no observations on the flow of this river are given. While, of course, it would be more satisfactory to show definitely in this case also the possible effects of head water reservoirs, it is not, however, a very difficult matter to conclude that, taking them at their best, little relief can be looked for from this source when the immense volume of the flood here is considered.

And, indeed, it may be stated generally, that the cost will not warrant the construction of head water reservoirs simply for the control of the river. It is only as they are a substantial addition to valuable water powers, as in the Upper Mississippi, or where their water is badly needed for irrigation, as in the case of the Missouri, that they have a claim to be considered.

Lower Mississippi.

Natural and Leveed Regimens.

But while the Lower Mississippi is practically out of the reach of effects from reservoirs at any of its head waters, still in its natural condition its alluvial valley presented a most striking instance of a great reservoir system of its own. Figure VII is a map of the

river from Cairo down, the shaded portion showing this area subject to overflow in high waters—in all about 30,000 square miles, or some three times the area of Lake Erie. This, in the main, is formed into a series of great basins. Upon the west bank, from Cairo to Helena, lies the St. Francis basin, while the Yazoo extends from Memphis to Vicksburg on the east. Below the bluffs at Helena, on the west, lies the smaller area known as the White River basin, ending a little below the Arkansas river, where the Tensas basin begins, extending down to Red river. Below the Red river, on the west, the overflow area is known as the Atchafalaya basin, and on the east, from where the bluffs finally leave the river, as the Ponchartrain.

In general, all along these basins, the ground slopes back from the Mississippi into an area of low swamps, threaded with lakes and bayous, and draining into such rivers as the St. Francis and Yazoo. Thus, as the Mississippi rises above the bank-full stage the flood excess is drawn off into these swamps, which act so far just as a system of great reservoirs. As, however, all the upper basins have their natural drainage back into the Mississippi, it is only above this return that the reservoir action is complete, while at their lower ends they do not hold but only retard the flood excesses that have been drawn off above.

This is the natural condition of the Lower Mississippi. However, during the last 15 years the States and Government combined have built up a levee system for the protection of these swamp lands, that now entirely shuts out the overflow from all but the upper one of these great basins, and that is beginning to seriously restrict it in that.

This levee system is shown on Figure VII in the heavy broken lines next the river; and, in order up, may be noted as follows: On the east, the line from the bluffs at Baton Rouge to the gulf shuts out the overflow from the Ponchartrain basin, while the line on the west, from below Red river down, closes the Atchafalaya. Above this, on the west, the line from a little below the Arkansas river nearly down to the mouth of the Red river shuts out the overflow from the Tensas basin, while on the east the line from Memphis to Vicksburg closes the Yazoo. The line from the bluffs, at Helena, nearly down to the White river closes the front of the White river basin, but, on account of the much smaller dimensions of this basin, at high stages it is necessarily more or less filled with back water from the Mississippi, and it is further subject to heavy overflows from floods in the White and Arkansas rivers.

All this then leaves open only the large basin lying on the west, between Cairo and Helena, and known as the St. Francis basin, while the levee, now in part closing this, is shown in the line ex-

ALLUVIAL VALLEY MAP OF THE LOWER MISSISSIPPI

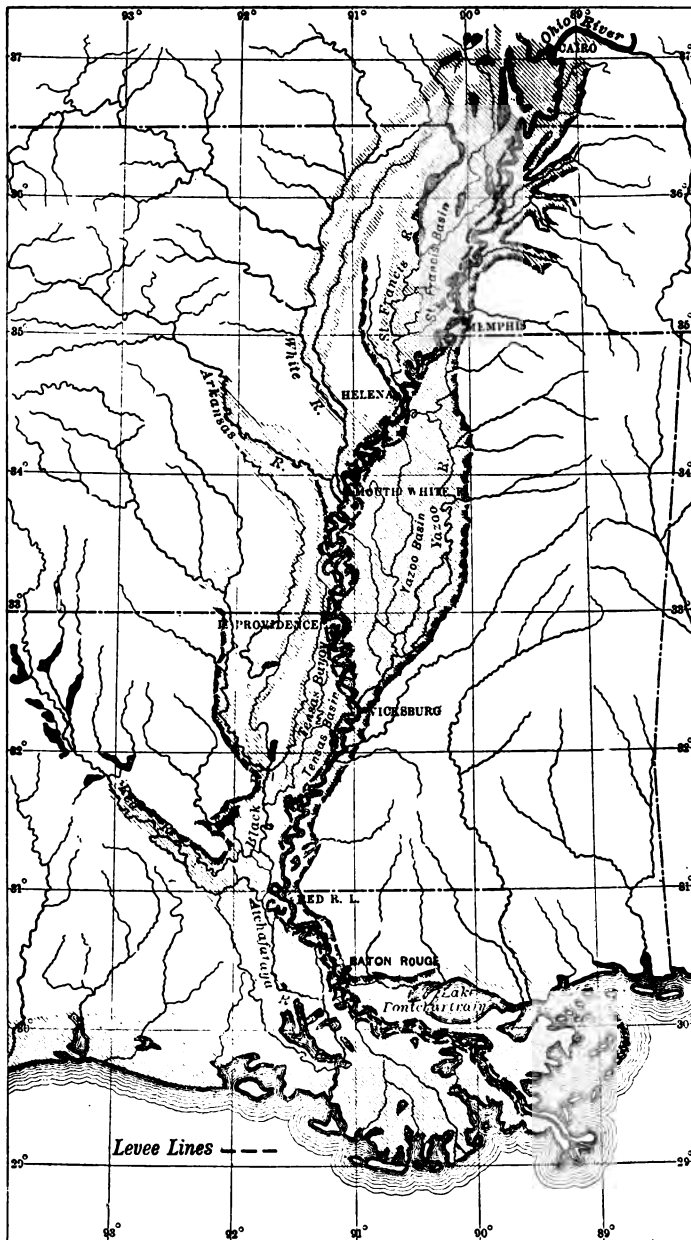


Fig. VII.

tending from the high ground at New Madrid down to a little above Memphis. This line, as first built, was much too low to withstand the increased flood heights that followed the restricted overflow, and the great flood of 1897, the first that has come against it, broke through the levee in a number of places before it had reached its extreme by several feet. But it, nevertheless, gave the last and the best indication of what flood heights may be expected when the overflow into this natural reservoir system is entirely closed out.

Figure VIII presents this contrast in the regimens from Cairo to Vicksburg of the great floods of 1882 and 1897, the first a condition of free outflow and inflow, and the second the condition of levee restraint above noted.

The scales in this case uniformly begin at the level of the 100 discharge, and mark the levels of successively increasing 100's up to the extreme high waters, while the shading here is again alternated with a cross-shading to show the levels of the same discharge all the way down the river as distinctly as possible.

The general character of the free outflows and inflows may be first noted in the 1882 flood regimen. The spill over the banks into the swamp basins begins to be marked at about the level of the 1,000 discharge or some 12 feet below the extreme stage of this flood at Cairo, which reaches there to about the level of the 1,700 discharge. This, however, is cut down by the outflow into the St. Francis basin to but little over the level of a 1,200 discharge at Memphis, while again the flood is brought back by inflow to the level of a 1,400 discharge at Helena in two crests corresponding with the Cairo crests, only some 12 or 14 days later.

It must be understood that these are but average discharge levels, while the actual extreme discharges of the flood may be materially larger. This is especially the case from Helena down where, between the draw of a free outflow on the one hand and the lake-like character of points in a complete overflow on the other, wide differences are found in the discharge at the same level in different periods. The inflow shown at Helena also in this case is clearly not the total inflow, since the outflow into the upper Yazoo at the same time is necessarily lost to the Helena stage and discharge.

Below Helena the flood waters from the Arkansas and White rivers, draining Division 4, Figure I, combine to make the conditions even more complicated. But the fact that the outflow here exceeds these contributions shows in the reduced discharge level of about 1,300 at the mouth of White river. And again, from there to Lake Providence, the double outflow into the Tensas basin on one side and the Yazoo basin on the other, cuts the flood extreme down to between the 1,000 and 1,100 discharge. While, finally,

Date	Description	Amount
1900	Jan 1	100.00
1901	Feb 1	100.00
1902	Mar 1	100.00
1903	Apr 1	100.00
1904	May 1	100.00
1905	Jun 1	100.00
1906	Jul 1	100.00
1907	Aug 1	100.00
1908	Sep 1	100.00
1909	Oct 1	100.00
1910	Nov 1	100.00
1911	Dec 1	100.00
1912	Jan 1	100.00
1913	Feb 1	100.00
1914	Mar 1	100.00
1915	Apr 1	100.00
1916	May 1	100.00

1. The first part of the document is a list of names and addresses of the members of the committee. The names are listed in alphabetical order, and the addresses are given in full. The list is as follows:

Name	Address
Mr. A. B. C.	123 Main St., New York, N. Y.
Mr. D. E. F.	456 Broadway, New York, N. Y.
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Mr. N. O. P.	9898 Ninetieth St., New York, N. Y.
Mr. Q. R. S.	9999 One hundredth St., New York, N. Y.

2. The second part of the document is a list of names and addresses of the members of the committee. The names are listed in alphabetical order, and the addresses are given in full. The list is as follows:

Name	Address
Mr. A. B. C.	123 Main St., New York, N. Y.
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the return flow from the Yazoo basin brings the flood back at Vicksburg to the 1,400 discharge level, notwithstanding the simultaneous outflow into the Tensas basin, as in the case between Memphis and Helena.

But, even without the above analysis, the marked effect of this system of swamp reservoirs on the flood strikes the eye in the first glance at it. From January 1, the beginning of overflow, to the latter part of July, when the river again gets within banks, all the flood extremes at Cairo are planed off by the outflow, and all the lower stages between these extremes filled in with it. That the basins can not hold this flood water back for the low water period is plain; from ten days to two weeks is about the retardation of each of them, and in a flood period of months it must practically all come out again on it. But even where it comes out, this reservoir system has considerably cut down the extremes in its leveling up process, while at such points of maximum outflow as Memphis and Lake Providence, it has about relieved the Mississippi of one-third of its flow, and a great river of some 500 or 600 discharge is carried down in the swamps outside of it.

Now, in contrast to this free overflow in 1882, the flood of 1897, subject to the levee restraint before noted, is certainly most striking. With an initial flood at Cairo some 0.3 feet lower, from Helena down the extreme high water stage is raised from 4 to 6 feet—and this notwithstanding the fact that a good part of the St. Francis basin was yet open; while the levee that was there gave way when the river was still some 200 to 300 below its maximum discharge. And again the flood, from there down in succession, broke through the Yazoo, White and Tensas levee systems in a number of places, pouring a great volume of its excess through the crevasses into each of these basins.

The magnitudes of these outflows may be roughly estimated in the various discharge levels reached by the crest of the flood from point to point down. Thus, with close to a 1,700 extreme discharge at Cairo, only about a 1,400 discharge is reached at Memphis, which again is brought back with inflow to the 1,700 discharge at Helena. This, however, breaks through the levees there before it has reached its extreme, and draws down the stage to a marked degree; while the levee system below has broken even earlier at about the level of the 1,500 discharge, and all the flow in excess of this, with the flood waters of the Arkansas and White rivers, are drawn off through these crevasses. Of this the outflow into the Yazoo shows again in its return at Vicksburg, raising the river there to the 1,600 discharge and holding it up to about that volume till the flow from above has fallen to between the 1,300 and the 1,400 level.

Altogether, then, from the evidence of this 1897 flood, there is

little doubt that to shut off the outflow completely from all these great basins, is to raise the high water stages of such floods from six to eight feet above the levels at which the natural reservoir system of this river would have carried them; and even in the interests of a *real* flood protection alone, it would certainly be wise to consider whether some less dangerous step into the unknown might not be substituted for it.

This substitute suggests itself at once in the inefficiency of the natural reservoir compared with the one under intelligent control; especially when the extremely low efficiency of this system of swamp reservoirs has been recognized. Two weeks has been noted as about the longest period that these basins would hold back the outflow and their inflows again form destructive floods at the foot of them. But had the St. Francis basin in 1882 simply been cross leveed at intervals, with outlets under control, making of it a chain of reservoirs to hold this flood water, there would then have been no return flow at Helena, no corresponding outflow into the Yazoo, no inflow crest at Vicksburg; and, while there would still have been some overflow, yet from Memphis down there would have been no great flood that year, and certainly nothing that a very moderate levee system could not safely have carried.

It is true that, in this case, reclaiming the swamp lands in the back of the St. Francis basin would have to be given up—some 4,000 square miles as yet unprotected and undeveloped. But this swamp land is not the only land in the valley. Even after the closure of these great basins is complete, their lower ends are still flooded by back waters, and with the higher stages of the restrained floods, in the White river basin at least, this may affect a good per cent of it. In the same way the chain of small basins on the east in the narrow strip from Vicksburg to Baton Rouge, would be altogether flooded by back waters even if their fronts were protected by levees, and this covers some of the best alluvial land in the valley.

In the similar strip between the bluffs and the river from Cairo to Memphis, probably some levee protection can be given, but the complete closure of the St. Francis front promises to seriously flood a large part of it. And, finally, there is the strip all the way down between the levees and the river that, with all points and islands, is cut off from any protection. This land, of course, is deliberately condemned to bear the more frequent and heavier inundations for the sake of the protection afforded the land back of it, and is certainly but a small fraction of the total area protected.

But all this area that is directly or incidentally drowned out by the complete closure of the great basins is not a small fraction of the 4,000 square miles in the St. Francis that would save it, and,

as the first now is, in the main, farms while the second is almost wholly swamps, it is alone a nice question of how much of the one should be sacrificed for the other. But the question does not stand alone; considering the increasing risk that each additional foot to the high water stages throws upon all the land behind the levees along the whole valley, there is very little doubt that holding the flood waters back, once for all, at the head of the system and never having extreme floods is true flood protection, even if it does sacrifice some 13 per cent of swamp area.

Referring to the flood regimen of 1882, it is seen that a system of cross levees, barring the slope to the south of the St. Francis basin, in all some 120 feet, is simply to take the Memphis flood of that year as the extreme to be passed through to the gulf in the place of the Cairo extreme. There are good reasons for passing the initial flood through to the gulf between levees without any further alternations of outflow and inflow, but to take the Cairo flood for this is to take an extreme discharge of 1700, in the place of the 1200 Memphis extreme, or about some 500 greater discharge to drown out the land below which is cut off from a levee protection, while greatly increasing the danger to all that is protected.

A levee system with the Memphis flood as the initial one would then pass the high waters at something between the natural extremes found in the course of the unleveed river. Flood volumes at points of maximum outflow, such as Lake Providence, would be larger, and less at points of maximum inflow, such as Helena and Vicksburg. The corresponding bed changes would also lie between these extremes, while the grade of the river would not be broken by alternating reaches of excessively increased and reduced discharges.

The nature of these corresponding bed changes may be recognized in the changes of the discharge scales from the floods of 1882 to 1897. Where the levees have increased the flood volumes materially they have, in general, lowered the levels of the low water flow; the levels of the high water flow as yet show little change, except a small depression at Lake Providence. The increase in the flood extremes of a complete restraint, then, simply promises a marked increase in the range between the low water and the bank level; and as one of the most serious problems of the Lower Mississippi is the erosion of a river that rises and falls some 50 feet against banks of light alluvium, the bed changes in this case are certainly most threatening.

Indeed, this matter of caving banks on the Lower Mississippi is only second in its importance to the flood protection and in fact, the two are closely related. In long reaches the bank erosion has its annual average of some 125 feet, that year by year eats its way

into the levee line, and a new line has to be constructed back of it. And not only has the river a sure mortgage on the land adjoining it, but there are few of the towns and cities along its course that have not a more or less continued fight with this movement of the river, to hold their wharfage and front properties, in which the river finally conquers.

Now, the bed changes corresponding to the case of the Memphis initial flood passed between levees, promise, at least, no general increase in the range between low and high water, and certainly no greater rate of erosion than that of the unleveed river. But this has so far taken a reservoir system, simply to hold back a natural outflow in years of extreme floods, and has not yet considered the case of filling the system annually from the top of all floods and returning the flow to the low water period. And certainly no other case is really to be considered, for, with a reservoir system in the St. Francis basin necessary, the first thing to do is to make the most of it.

As in this the flood excess must be drawn off through artificial outlets, there is no need of flooding the river front with it from Cairo to Memphis; it should be drawn off from as near Cairo as possible. And as the whole question is the capacity of the reservoir system, the extreme flood is in no way limited to the 1882 extreme at Memphis. The matter is to be taken up simply as a problem of reservoir capacity and flood excesses, with the view of seeing what can be reasonably done with it, both for the highest degree of flood and bank protection that can be gotten, and the greatest improvement to the low water navigation.

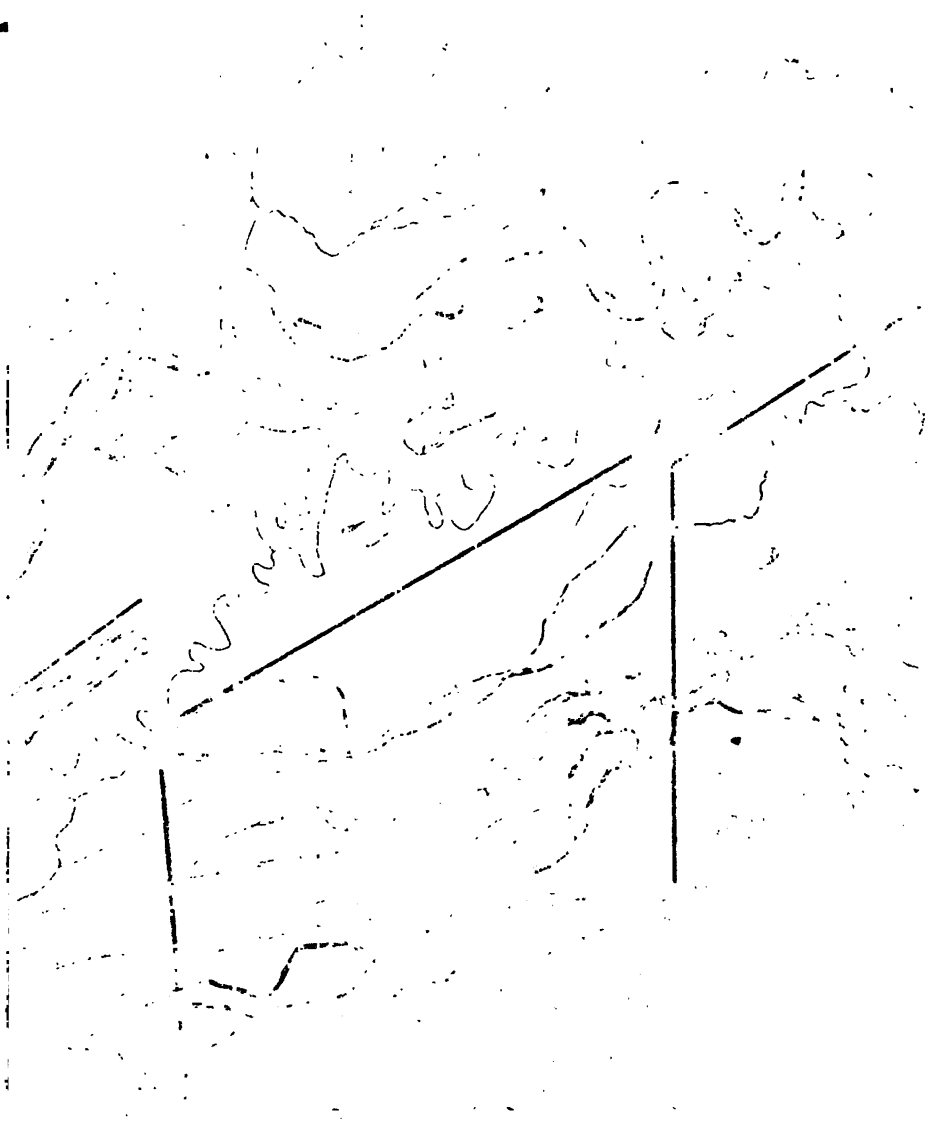
St. Francis Reservoirs.

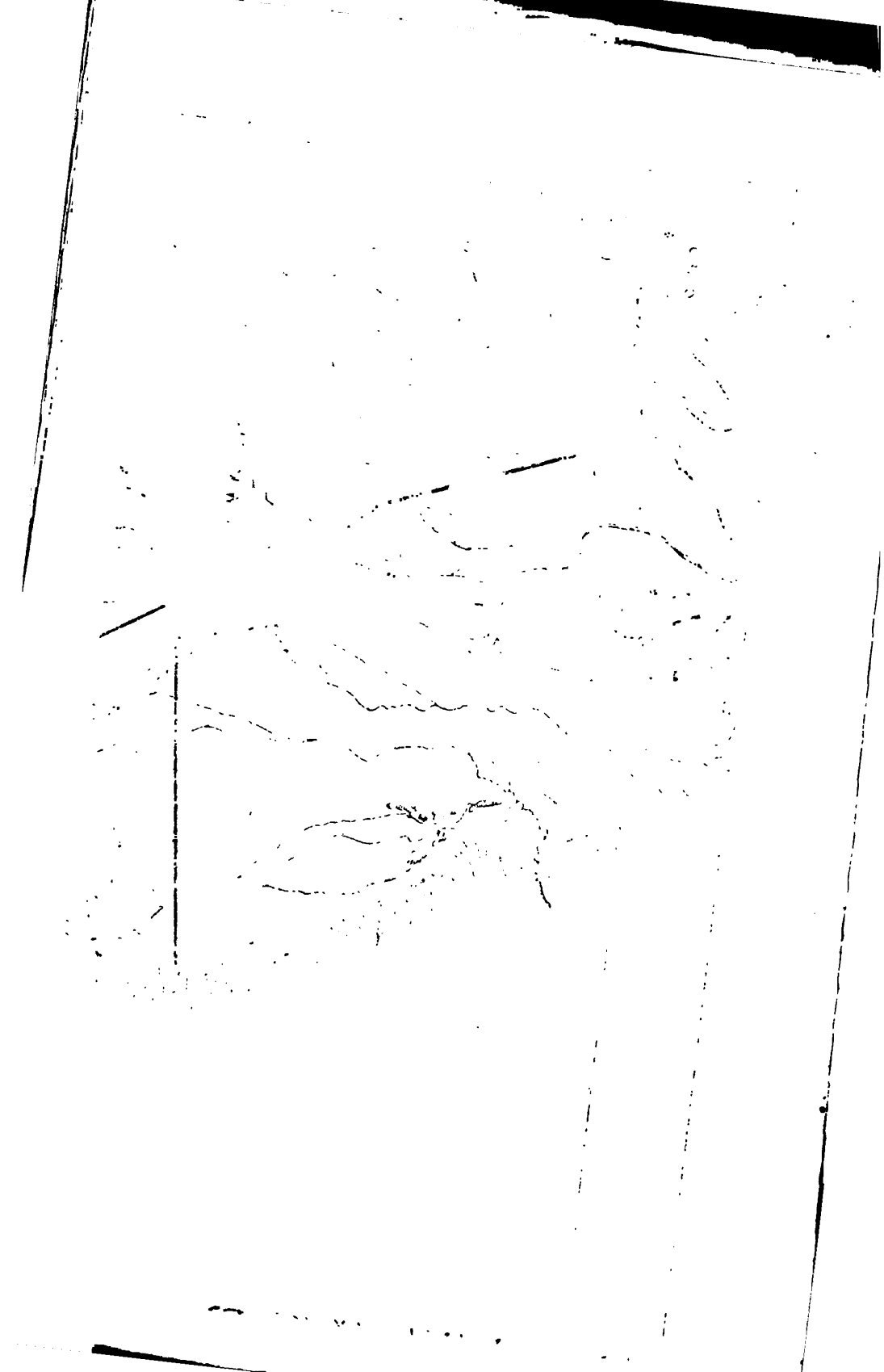
Figure IX is a map of the St. Francis basin on which such a system of reservoirs is outlined. Of course, no actual location of such a system can be given without a topographical survey of this basin, which has not yet been made. However, enough of its general form is known to fix the type and set the scale of the reservoirs required. Thus, the basin has a more or less uniform tilt to the south, with a total fall of some 120 feet from Cairo to Helena, as shown in the "Sketch of general profile" given. And, not to exceed the limits of earth embankments, it is seen that a chain of at least some six reservoirs to divide up this fall will be needed here.

Again, the "Sketch of general cross-section" shows the lay of the ground from the river across to the bluffs forming the western boundary of this basin, and in this the general type of the reservoirs is clearly indicated. Each should have a levee on the east, limiting the swamp area to be used for this purpose and holding the water in the back or lower portion of the basin. This longi-

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tudinal levee begins on grade, taking in the natural drainage from the river to the swamp at its upper extreme, and rises as it goes down with the southern tilt of the basin, till it reaches at its lower extreme the height of the levee that crosses the swamp and closes in the whole reservoir against the high ground on the west.

These lines crossing the swamp would, of course, take advantage of all the high ground that they could follow. They would undoubtedly require heavy work in places, but probably no heavier than some of the front lines on the river already constructed. At the points also selected for the lines of movable dams by which the reservoirs would be filled and emptied, the work would be formed of masonry founded on piles, but in the rest of the line it is thought that earthwork would answer the purpose; or that they would be just what they have been called, cross-levees.

Perhaps, for safety, this should be an especially strong levee, but it does not seem probable that an occasional break here would be any great calamity. It would drain out the reservoir in which it occurred, and would have to be repaired just like a crevasse, but with the provision for rapid filling that the whole system would have, it would seem that it could be drawn off below without endangering the lines following it; while it is only in the event of its occurring just on the top of a great flood that running it out into the Mississippi would make a high water there of any importance.

At the head of this system of reservoirs the outlet for drawing off the flood waters would be located. For this a line of movable dams on the west bank of the Mississippi, just above its junction with the Ohio, would be required. The base of these would be set at about the level of 30 feet on the Cairo gauge, or altogether above the sand movement in the bed of the river; and they should have a range of some 10 or 15 feet in their adjustable crests, fitting them both to fill the reservoirs from the flood periods of any year, or to draw off the extreme excesses of the occasional great floods.

From these dams the outlet would lead back from the river, following some such line as the location shown, first into a double reservoir to the east and the west of the New Madrid high land, and joined by a cut through this high land as indicated. The reservoir on the east would be held between this high land and a line of levees from the outlet down, enclosing such of the swamp lands in the New Madrid basin as might be taken for this purpose. For this reservoir, also, it would be necessary to provide for emptying it back into the Mississippi at low water just above New Madrid.

The one on the west, on the other hand, forms the first in the regular chain of six or more reservoirs extending from Cairo to Helena, as outlined on Figure IX. These all fill and empty in

succession through each other as in the ordinary slack water system of a river. And whatever increase in the navigable depth may be given from Helena down, by emptying the reservoirs on the low waters, it is plain that any navigable depth that may be wanted may be readily carried from Helena up to Cairo through this slack water system. All that is needed is putting in the locks with such dredging, once for all, as the given channels may require.

Without the topography of this basin the capacity of such a reservoir system can, of course, only be roughly estimated. But, covering as it does an area of some 4,000 square miles, or about two-thirds of the flooded lands on the west in this division, it is plain that every foot added to the height of the levees is an immense addition to this capacity. It is thought, therefore, that an average storage depth of some 15 or 16 feet may be taken as a capacity that could be reasonably gotten, without going beyond the character of the work outlined.

Taking this capacity, then, at $4000 \times 15.5 = 62,000$ square mile feet; and this divided by 310 equals 200 days' discharge of a hundred thousand cubic feet a second. With this the reduction of any flood at Cairo, that filling this reservoir system would give, is very easily estimated. It is only necessary to scale the number of days in the successive 100 discharge levels of Figure VIII from the top of the flood down, until the sum reaches this 200 value, to get the level to which this reservoir capacity would cut it off.

This, for the given 1882 flood, is reached at about the level of 42 feet on the Cairo gauge, or, altogether, the reservoir system would have cut this flood down some 10 feet at Cairo. And this is about the least that it would ever do, while in floods of less duration or lower stages, its reduction would be distinctly greater. Such a reservoir system, then, may be safely counted on to cut some 10 feet off the top of the Cairo floods in all cases; while the return of this to the low waters at Helena would about triple the flow there, or add some 15 feet to the extreme low water stages.

In the operation of this system of reservoirs it may be noted that the flood at Cairo is generally in sight far enough ahead to know just about what flood water should be drawn off. In the promise of a great flood the plan would be to regulate the crests of the weirs at the head of the outlet so as to hold down the stage to an estimated maximum. With the given capacity, this maximum for the greatest floods would be about the equivalent of a Cairo stage of 42 feet, while correspondingly lower stages would be taken, as there was less and less promise of a great flood.

The only condition that would present any difficulty would be that in which the promise of a great flood was unusually delayed,

and where in the interests of the low water navigation the reservoirs had been partially filled from earlier rises. In that case, when the promise of a great flood did come, it would be necessary to run out the reservoirs to get ready for it.

In this connection it should be noted that while it takes a rise some four days to pass from Cairo to Helena by the river, the slack water system can take any difference in discharge over this interval instantly. In addition to the week or ten days in which the promise of a great flood was in sight from Cairo, there would also be these four more days in which to run out the reservoirs at Helena. By being careful, then, not to take more water from the earlier periods than might be necessary to insure full reservoirs, in every case certainly nearly, if not all, the full capacity of the system could be counted on to draw off simply the excesses of the great floods.

One point, however, in regard to this reservoir capacity, perhaps, here deserves a further notice. Of course, any reservoir system that is operated with sediment bearing water will in time fill up. But the experience with the settling reservoirs of city water works and the sediment observations taken, make this rate of filling up here fairly well known; and with the one filling a year it would be several hundred years before a serious reduction in the capacity could be looked for from this cause.

This puts the matter at once out of the range of practical questions, but, to those who still like to look so far ahead, it may be interesting to note the probable course of the system in this distant future. The filling up with sediment would, of course, be largely concentrated in the upper part of the system, and by directing it as far as possible into the New Madrid reservoir that might, perhaps, in something over a century, be turned out again as an agricultural district; but a level now composed of the alluvial cream of a continent altogether above the plane of high water instead of below it. One by one, in the same way, the reservoirs forming the chain from Cairo down would follow this course; preserving, however, the channels through them for the slack water system of navigation and for filling below.

The final outcome in something over a thousand years would be a wholly filled up swamp with a double channel for the Mississippi; the front carrying the ordinary river, the back one used as a slack water system and discharging the flood excess at Helena from level to level with its form of immediate transmission. But how far the developments of that day might make a further extension of this down desirable, must be left to the man of that distant future to determine.

Returning, however, to present conditions, it is plain that with such a reservoir system so operated, the flood regimen would be

quite different from that of the case first considered, where only the natural outflow into this basin was to be held back. True, at Memphis the extreme flood would not be greatly changed; in the place of the 1,200 discharge there this reservoir capacity would cut the top of the flood down to about 1,100 or to a 32 foot stage on that gauge; but the ordinary flood would be much more markedly reduced.

With no change, then, in the low water flow except the small contribution from the New Madrid reservoir, from Cairo to Helena, the river would be a case of about the present low water regimen with uniform but markedly reduced floods imposed upon it. And changes of bed might be expected to follow this change in the flood regimen; but there is no reasonable doubt that they would be altogether in the direction of a better river.

But at Helena the wholly new regimen begins. With some 10 feet cut off the top of all floods there, and this hundred thousand cubic feet a second for two hundred days to put back on the short low water period of this river, the range from high to low water even in extreme floods would be little more than 25 feet, while its ordinary rise and fall would be near 15—in contrast with the condition of a complete levee restraint with its ordinary range sometimes over 40 feet, and an extreme range of more than 50.

This reservoir system simply cuts the extreme flood off about to the bank level as far down as the White and Arkansas rivers, where the contributions from these tributaries may be expected to again raise the high water line; and a moderate levee system is required for a complete flood protection from there to the gulf. However, the levee system already completed here, is certainly enough for any possible contingency, while there are possible contingencies in the combinations of these lower floods with a complete restraint from above, that no levee system yet considered would begin to stand against.

But in the same connection the difficulty of keeping up a levee system on the caving banks of this river is also to be considered. What the rate of erosion would be in the greatly reduced range of stage effected by the reservoirs is, of course, not known; but the problem of bank protection is something like that of the retaining wall. It may be cheap and easy at ten to twenty feet, and extremely difficult and costly at fifty; and it is not unreasonable to expect that the reservoir system would reduce this difficulty to a small fraction of its present proportions, even if it did not entirely remove it.

With the banks also reasonably stable, the one great difficulty in the way of channel works for improving the low water navigation would be removed. For otherwise, to put such works in the river,

with this lateral movement of the river going on, is to put them where in a few years at best they would be useless, if indeed, they do not become absolute obstructions. But with the greatly reduced erosion on the one hand and bar building on the other that this new regimen promises, and some 15 feet added to the stages of the low water flow, a navigation altogether beyond the range of anything that has yet been considered possible is already secured without any channel works whatever.

So far as navigation is concerned, this reservoir control simply opens a highway for ocean commerce right into the heart of this continent. But what such a thing may mean to a country is probably the last thing that the country begins to realize. Unlike the flood and the bank protection that serve immediate interests, with like aids to existing navigation, this is an interest which does not yet exist; and the great body of the people that are to be affected by it are slow to realize the possibilities that lie in such a creation, even where they have a parallel of it right under their eyes.

Were the lake control of the St. Lawrence water-shed eliminated, a canoe could hardly have reached Duluth in the natural river; and that city would have been impossible, with Chicago probably never heard of, and Cleveland and Buffalo but way stations on single track railroads, and the grain of the Northwest would have been locked in, and the ores of Superior, that are making this nation the ironmaster of the world, hopelessly sealed in an utterly inaccessible interior for centuries.

These are matters that are the province of the statesman to foresee, and governments to create; and it is simply the opening of such a line of commerce from the gulf up, that is here proposed; and this also made on exactly the same principles. Of course no such great areas are to be sacrificed to it—the reservoirs are to cover less than half the area of Lake Erie—but they have their power of control multiplied by ten in the 15 or more feet annual oscillation that is given them to replace the foot or so of like oscillation in the lake levels.

That this natural system of the North would be joined to the artificial one of the South may be counted on, and a line of internal seaboard right through the center of this country would then mark the earlier decades of the new century—a creation whose far-reaching utility is quite a different thing from fostering waterways, with or without traffic upon them, for the avowed purpose of controlling freight rates. It is such commercial arteries that make a cheap distribution possible on the network of railroads that spring from it, and at the same time make their business pay.

Comparative Costs and Estimates.

Before considering estimates of the cost of such a reservoir system in the St. Francis basin, a brief outline of the estimates of alternative projects, reached after some twenty years work on them, may be first taken for comparison. For of course, doing anything with a river over a thousand miles long and a mile wide, is a big undertaking.

On the levee system for flood protection the states have spent in round numbers some \$35,000,000, and the general government \$15,000,000, while it is estimated that an expenditure of \$20,000,000 more will be required to finish the work, putting the whole system in shape for a complete flood restraint. After this, it is estimated that to keep the system up will cost in renewals and repairs some \$2,000,000 annually.

In the matter of a general bank protection on this river the net result of all expenditure has been simply to bring the river engineers to look upon it as practically a hopeless undertaking. Repeated failures, year by year, have shown the need of heavier work over wider areas to hold these banks against erosion; and it was not until a protection that cost some \$30 per running foot was reached that even a reasonable degree of success was met with. With this, a system of bank protection has been variously estimated at from \$60,000,000 or \$70,000,000 up to \$120,000,000, with from 5 to 10 per cent annual repairs.

These estimates differ mainly in the number of miles of bank to be covered that such a system would require, and, of course, where there is such a wide margin of uncertainty the thing can hardly be called an estimate. But as both of the extremes were alike taken simply as the ground for finally giving up a general system of bank protection on this river, it is probable that no experienced engineer, who had in view actually doing the work for the money, would take the costs at less than 500 miles of bank at \$30 per foot, or, say, \$80,000,000 with \$5,000,000 annually for renewals and repairs.

However, even with a general bank protection given up, there is a continued call for large expenditures in this line, protecting concentrated values on town fronts, and special bends that threaten a cut off. But how far the river, left free to change its course at will in the reaches above, will come in time to flank these local works and cut them all out is still a problem.

With the system of bank protection given up, of course channel work for the improvement of the low water navigation goes with it. For, as before noted, to put such works in the river without at the same time holding the river in its place, is to put them where they can do no permanent good, and may come to be very much in the

way, if they are not cut out by the river in its channel changes. The question of whether any material improvement to navigation in this river could be gotten at reasonable cost by works of this character has, therefore, as yet hardly been touched; but as it is barred at its beginning by the excessive cost of bank protection, it is not much of a practical question anyway.

But government works on navigable rivers can hardly ignore the interests of navigation altogether, and to meet the case thus presented a very extensive system of dredging low water channels has been inaugurated. The task is admittedly an endless one, for each high water obliterates the work of the low water season preceding it. But as a development in hydraulic dredging, and for the capacity attained of moving large quantities of this bar material in short times, it is certainly a great piece of engineering.

But even with the fleet of powerful dredges now engaged in this work, the actual improvement to the low water navigation that can be gotten is necessarily quite limited. With the bars often several miles in length, cutting low water channels through all of them, over the 600 miles of river between Cairo and Vicksburg in this short low water season, is not a task in which any great addition to the depth can be attempted, and perhaps an average of some two feet increase may be taken as its limit. For this an annual expenditure of \$200,000 to \$300,000 is estimated, including repair of plant and percentage for its renewal.

Now, in contrast with the estimates above, the cost of the St. Francis reservoir system is to be considered. And while, of course, such costs in advance of an actual survey and location of the work are necessarily but rough approximations, they are, nevertheless, estimates of plain construction outside of the river, and may be counted on with much more confidence than any estimates which have its destructive forces to deal with.

Each of these reservoirs may be then taken as formed of 25 miles of cross levee at \$90,000 per mile, and 25 miles of longitudinal levee at \$30,000, or an average of \$3,000,000 for the earthwork in each of them. This \$90,000 per mile will build at average prices a levee altogether heavier than the standard section, safe for some 25 feet of water against it; while the longitudinal levee is proportioned to run from grade up to it. This estimate, however, takes it simply as team work, while it seems probable that it could be built with hydraulic dredges, in which case it would be at least a third cheaper. In addition, the filling and emptying systems would take an average of some 2,000 feet of movable dams at \$200 per foot, and 2,000 feet of fixed weirs with flash boards at \$150 per foot, or altogether \$750,000 to the reservoir, making the total estimate for the six reservoirs, \$22,500,000.

For the flood water outlet, the weirs at its head should have some 6,000 feet of movable dams at \$300 per foot, or \$1,800,000, while the channel leading back from it would require about 100,000 square feet in the area of its cross section. This, as soon as the grade permitted, should be taken with about one-quarter of its section in cut and three-quarters in embankment, and would be hydraulic dredge work altogether. Probably from \$3,000,000 to \$4,000,000 would be a full allowance for it, but without a location and levels very little in the way of an estimate can be made of it.

In the matter of damages the area to be flooded is now some two-thirds land and one-third water, and taking the 4,000 square miles altogether at a dollar an acre, which was formerly a good price for swamp land here, makes it \$2,560,000. Or, again, the testimony before the sub-Senate committee in 1898* put the estimated value of all the land in this basin at \$8,600,000, and probably three-quarters of that, at least, lay in the high ground next the river that is left outside of this reservoir system. With a promised protection of this area, then, once for all stopped, it would seem that some \$3,000,000 was a fair estimate of the actual land values sacrificed in this work.

However, it should be distinctly understood that every dollar the government has spent and is spending on the front levee line in this promised protection is probably adding ten dollars to this item in the cost of a reservoir system here. And what, perhaps, is even more questionable, in the place of taking the land as it is, it is leaving it to be sold for farms by speculative interests at large profits, to be taken from its final owners when the educational flood at last comes that makes the necessity of this reservoir system fatally apparent.

A summing up now, of these items, for the total cost of this reservoir system gives:

Six reservoirs, complete,	\$22,500,000
Outlet, weirs and excavations, say . .	5,500,000
Land damages, say	4,000,000
<hr/>	
Total, . . .	\$32,000,000

This, however, has not yet considered the development of the system of slack water navigation through the reservoirs from Cairo to Helena. With this a link in a great commercial highway, the locks, of course, should be of ship canal dimensions and would be large works, costing some \$2,000,000 each, or \$12,000,000 for the six of them. These, of course, should go in with the construction

*55th Congress, 3d session, Senate Report No. 1433, page 436.

of the reservoirs, but dredging the channels here could be done as it was needed. And, certainly, in the place of cutting low water channels that fill up each season, the fleet of government dredges could be profitably set to cutting a channel, once for all, here that would not fill up in a century.

For a general summary, then, of all these estimates, existing projects call for:

FLOOD PROTECTION—\$50,000,000 expended and \$20,000,000 more estimated to complete it, with \$2,000,000 yearly for maintenance.

BANK PROTECTION—\$80,000,000 estimated to complete it, with \$5,000,000 yearly for maintenance. This, however, now given up.

NAVIGATION—Permanent improvement; given up with bank protection, but \$250,000 to be spent yearly in dredging to give some two feet greater low water depths.

ST. FRANCIS RESERVOIR SYSTEM—Cost, \$32,000,000, and gives:

Flood Protection: Complete; no cost of maintenance; saves from 1,000 to 2,000 square miles of cultivated land otherwise drowned out, and greatly reduces the flood risk to the whole valley.

Bank Protection: Little, if any, then needed; probably a fraction of the cost of maintenance in the other case would in this case fix the whole river permanently.

Navigation: From Helena down, at least doubles the extreme limit of navigable depths aimed at in existing projects if, indeed, it does not more nearly triple them; and opens an extension of a like navigation from Helena to Cairo at present cost of \$12,000,000, with dredging to follow as needed.

Finally, it may be noted that in the last 20 years the government has spent on this river some \$40,000,000, or just about the cost of the St. Francis reservoir system with slack water navigation to Cairo. That it has spent the most of this to pay for experience is now generally admitted; and it may also be admitted that, perhaps, it could not have gotten this experience any cheaper. But, in any event, if the matter was worth beginning it is certainly now worth finishing with such a waterway in sight, carrying as it does this high degree of flood and bank protection with it. The final question then is simply: Having paid \$40,000,000 here for experience, does the country now propose to profit by it?

THE LAKES AND GULF WATERWAY.

Cairo to Lockport.

BY LYMAN E. COOLEY.

The importance of Mr. Seddon's paper cannot be over-estimated. It is the summary of twenty years of experience, the residual analysis of the enormous mass of data gathered in that period and the epitome of forty millions of expenditure, and it takes its place in the array of results from less ample fields.

The possibilities were boundless and the lessons to be learned justified the cost. Though doomed to ultimate disappointment, the optimist was best adapted to push theories to the limit. Out of it all should come knowledge, a wise program and encouragement. The professional world is entitled to an exhaustive monograph which shall set forth the data and expose their bearing. Such presentations by master minds have made epochs in scientific annals and turned the thought of the world. But in the changing personnel of military policy and the expediency so often lurking in civilian service, is not this hope to be indefinitely deferred?

For three-fourths of a generation has Mr. Seddon devoted himself to physical research of the Mississippi river and its tributaries. He is the saving remnant from among a number of early and enthusiastic workers. That he should give his time to exploiting his researches in this and other papers, is a matter for congratulation.

It is refreshing to return with a broader view to first principles, after the exhaustive threading of by-paths through the underbrush of detail which usually close near the starting point. The river is the physical expression of the forces that made it, the climatology, topography and geology of its basin, and its features are accidental only in a narrow and restricted sense. Any material change of a permanent character must, therefore, be produced through a change in the determining conditions.

The immediately related factors are the declivity, the volume and the variations therein, and these express themselves in what may be called the physiognomy of the stream bed.

An excess of energy from declivity produces a dissipated stream bed. To artificially constrain this within narrow and uniform limits eventually results in a lower declivity; but the period of transition is long, the works must follow down to lower planes and the improvement in navigable depth is meantime uncertain. These relations have been understood (academically) from the outset. An

early advocate talked of setting Cairo on a hill. Abroad, works of rectification have been in progress for generations, partially to fix river banks in the interest of marginal lands, resulting in deeper pools with little change in bar depth and a re-arrangement of slopes which, in their final adjustment, involve a long period of time. This has led to the breaking up of pools by the construction of artificial bars, called ground sills, so as to better distribute the minimum depth and proportion the resistance to the declivity. It has also led to a recognition of the propriety of taking out a part of the fall by means of dams and regulation on the lowered declivity.

In the case of the Lower Mississippi, it was contended that there are certain anomalies in the low water profile that could be corrected without disturbing the regimen as a whole, as in the New Madrid, the Osceola and the Lake Providence reaches. The results of the works at these localities may not be conclusive, but are so accepted by many, though good water seems to have prevailed through the Osceola reach for several years. The cost, however, has been very great.

In the interest of navigation, solely, the policy has been experimentally developed of maintaining a minimum depth of nine to ten feet across the bars by means of hydraulic dredging. These cuts are made on the falling stage and are found to persist through the low water season when judiciously located, but are obliterated by the following high water. The cost is estimated at \$200,000 to \$300,000 per annum, which certainly is a small sum in proportion to the cost of maintaining the roadbed of a railway for the same distance and for an equivalent traffic.

In former times and in extreme low water years forty-three places below Cairo were liable to depths of less than ten feet, twenty of which might have less than seven feet and thirteen of these five feet or less. Above Cairo a number of places were liable to depths of four feet or less, though a material improvement seems to have been made by regulation below St. Louis, with a concentration of slope in the reach above the city.

There seems to be a reasonable assurance that, by means of hydraulic dredges, the river can be maintained at a limiting depth of nine to ten feet below St. Louis at a cost amply justified; and this fact is very important as maintaining a live interest in the stream until such time as a broad public policy will deal with conditions that shall work a permanent change for the better.

If a material change in the relation of bed to declivity in this great river is beyond the limit of practical achievement by regulating works, there is yet to be considered a change in conditions as to variation in volume. The stability of regimen due to uniformity

in flow needs only to be stated. Everyone recognizes the equalizing effects of lakes, swamps and woodlands; and the remedial effect of reservoirs early suggested itself.

The river bed itself is a great reservoir, which modifies a flood in its course, and this action is supplemented by high stage overflow, the effect of which is to prolong the floods near the bank-full limit. If these high stages were long continued, which would be an approach to uniformity, no doubt the bed would conform with a sufficient capacity; but they are too short in duration for a full response, and the necessary result is overflow in rivers varying widely in volume. The bank full limit is the practical measure of the working forces involved. To reduce the maximum and increase the minimum, though the total energy remain, is to apply the forces between narrower extremes and inaugurate a radical change in conditions for the better.

The natural overflow reservoirs of the Lower Mississippi return their volume to the stream often at inopportune times, and to the detriment of the reaches directly affected; nevertheless, the aggregate result through the ages has been a substantial regulation of volume below Red River and a prism of most economical form on a moderate declivity. Since man entered on the alluvial lands, over 160 miles, or more than 20 per cent, of the length between Red River and Cairo has been lost by cut-offs. Nature's efforts at stability under overflow conditions, by reducing the energy through distribution, have been defeated. All the energy due to this shortening, increased by efforts at flood concentration, has been thrown into dissipation of stream bed, with perhaps an eventual recovery of length at tremendous sacrifice of land for a new location in part.

The natural wealth in these alluvial lands is so great that every one concedes their reclamation as a condition precedent, whatever the results to the regimen of the river. The levee was the obvious individual recourse, gradually expanding into collective effort, then developing state control and enlisting national patronage, and now reaching the final stage of national responsibility. This is but a natural evolution by reason of the wide forces involved, and it would be strange if these great purposes had not unconsciously fathered theories of river improvement more or less cogent.

The levee theory proceeded on the assumption that by confining the entire volume to the channel, the stream bed would thereby be deepened; but the additional energy refuses to discriminate in favor of the bed as against the banks. This added energy is largely a force of dissipation, already in excess under overflow conditions. Efforts so far developed show the necessity of greatly increased levee height and strength for the full control of extreme floods; but whether there will be an eventual lowering of the

flow line if the system were fully developed, and whether in such event it can meantime be maintained, are matters of hope rather than demonstration. The disastrous experience of the centuries with the great rivers of China may not be in point, for no adequate research into conditions from the modern standpoint has been made.

In any event the tendencies are adverse, especially from the standpoint of navigation. A broader and more variable bed, wilder wandering and more eager bank erosion and greater discrepancy between bar and pool depths, are likely to attend on the accentuation of extremes.

The levee policy is the converse of the project of Mr. Seddon. Rather than increase the maximum volume flowing in the river, he proposes to greatly reduce the same by drawing off and storing, once for all, the excess of volume above bank height that is now drawn off and returned to the river repeatedly between Cairo and Red River. This is to be done near Cairo, and some four thousand square miles in the St. Francis basin are to be appropriated for a series of reservoirs.

These reservoirs are to have such capacity that the flow in the main river may be practically restricted to the bank-full stage, so that no further development of the levee system will be required. The volume drawn off at high water is to be restored at Helena on the low water stages and is calculated to produce a navigable depth below of not less than twenty feet, which is to be carried up to Cairo by slackwater through the series of reservoirs. It is estimated that the range in stage below Helena will be reduced from about fifty feet under full levee conditions to some twenty-five feet, thus greatly reducing the problem of bank conservation. In non-overflow years it is proposed to draw from high water and fill the reservoirs in the interest of low water navigation.

The marginal lands that will thus be available are considered as an offset to part of the area that will be appropriated, and much of the remainder is of little value or irreclaimable. The questions of sedimentation and control are fully set forth in the paper under discussion.

The carrying out of such a project would reduce the present ratio of volume between flood and low water from 12 to 15, to something like 4 to 5. So great a step toward uniformity promises radical changes in regimen aside from the mere taking off of a high stage and the adding to a low stage. The narrower range in volume should assimilate the high and low water regimens, now radically divergent; the bed conformation should change in favor of a

greater depth on bar in respect to pool and tend toward a lower declivity, and the smaller range in energy and in stage should greatly lessen bank action.

The project of Mr. Seddon promises so much, and so fully recognizes the primary dynamic conditions, that it should receive the most serious attention and exhaustive investigation as to the actual possibilities of the site and the treatment proposed.

So much for the local reservoir treatment of the Lower Mississippi.

Some consideration of broad questions of public policy is useful as a hindsight for matters within the range of early achievement.

Civilization in organized communities dawned in the use of waters on arid lands. From immemorial time, actual and beneficial use has determined proprietorship. The doctrine, no doubt, developed in those necessities of the state which required the fullest development of limited resources, and is not unlike that of the school of economics that would vest the control of land only in the actual user.

The same doctrine obtains in humid regions, so far as demanded by public necessity, as in the appropriation of water for domestic and industrial uses, for the supply of cities, for purposes of navigation and, in a restricted sense, for water power, subject only to the limitation that riparian enjoyment shall not be needlessly and willfully impaired. The extent and nature of appropriation is a matter of public policy.

The conservation of water for beneficial use has been long advocated by the writer, not only in the great lakes and other natural reservoirs, but in artificial reservoirs wherever the situation invites. These views have been strengthened by recent studies in the arid regions, and now a far reaching public policy seems to justify the conservation of waters to the fullest practicable extent. The writer, therefore, demurs to that general inference of the paper under discussion, which seems to deprecate the control of head waters, and assumes that it was only designed to show that the effect would be relatively small and indirect for the specific purpose under consideration.

It may be admitted that extreme head waters often, perhaps generally, contribute little to the maximum flood in the outlet of the basin, their function being rather to prolong the stage, though much depends on the relation of the basin to storm tracks and other facts of climatology. By parity of reasoning, the control of such waters would not greatly affect overflow at remote localities. On the other hand, the contribution to low water is an actual and

potent factor to the extent of its volume from the point of origin to the sea. Again, conservation carried to attainable limits in a large basin would profoundly affect both high and low water flow throughout both the tributaries and the main outlet.

The exception is in the arid region where public necessity will eventually consume all water. There are some 800,000 square miles in the United States without sufficient moisture for profitable tillage, and if all the water be economically utilized not over 12 to 15 per cent of this area can be reclaimed for agriculture. Such development demands the storage of all surplus waters to the time of most beneficial use, and such policy will prevail so far as conditions admit. Rivers originating in the arid regions may therefore be dismissed from this consideration, except as to their humid sections.

It is possible to store in the upper lakes, without undue fluctuations, the variation in volume, or the surplus above the minimum flow at Niagara, and divert, perhaps, 100,000 cubic feet per second southward. With such added volume a waterway could be produced from the lakes to the Gulf of Mexico that would work a revolution in transportation conditions on this continent, and power would be created for industrial development in the very bread basket of the continent. As the minimum substantially measures the utility of the eastward flow, the interests vested in the natural conditions in Lake Ontario and the St. Lawrence would not be materially impaired, and corrective works and a radical improvement for navigation would be facilitated. The possibilities are so well within the resources that might be applied that to become practicable requires only public conviction.

It is possible to divert to the lakes many headwaters of the Upper Mississippi and the Ohio, probably tens of thousands of miles, and divert an equalized flow through a new outlet without greatly disturbing the flow in the natural outlet. Could such diversions be as great as 100,000 miles, they might reduce extreme flood volumes by 10 per cent at Cairo, provided these diversions were so distributed as to admit the theory of normal basin ratios. The effect would be larger up stream, and, locally, floods would be quite suppressed. Such diversions could well form part of a general policy of conservation.

Suppose it were practicable to devote the equivalent of one section in each township to reservoir use, and store therein a depth of twelve feet. The average run-off may be taken at one foot; it will be less for the Upper Mississippi and greater for the eastern Ohio. This reservoir would store one-third the total run-off for a year, but it is assumed that local utility demands a continuous and

uniform flow. Under average conditions of precipitation in humid regions, a cistern of a capacity of about one-third the total rainfall on a roof is sufficient to distribute the same in a uniform flow. On land a fraction only of the precipitation runs off; it accumulates in snow, and is consumed at other seasons by vegetation, by evaporation and by percolation and absorbed by an arid soil, and the seasons vary greatly. So it will be conservative to assume half the average run-off as under control.

The effect of such a system throughout a basin would be to quite do away with some, and greatly reduce all, floods, and there would be established a minimum flow of not less than half a foot for each square mile of watershed, substantially in addition to the natural flow generally existing. These conditions would obtain not only in the main outlet, but in every tributary and in every creek leading to a reservoir.

The possibilities of navigable development become unlimited, and water power becomes everywhere available. Value is everywhere attached to lakes and running streams for general utility and as objects of beauty and pleasure. Sections of China by fish culture produce more food than from equal areas of land, and even the Illinois river for several years has produced a fish crop that has sold for more per acre than have the farm products of Illinois. The compensations for the land used are many.

The opportunities for storing water are endless when enlightened public policy shall make the need apparent, and the benefits to be derived are only less than in arid regions. No other development is conceivable that is charged with larger possibilities for the common welfare.

From Lake Michigan at Chicago to the mouth of the Ohio river at Cairo is 550 miles in round numbers, and it remains to discuss how twenty feet may be carried to that point to meet the project of Mr. Seddon and make a through route of that navigable depth from the great lakes to the Gulf of Mexico.

The "Chicago Divide" is in reality a deep cut valley across the rim-ridge of the lake basin, and is known geologically as the Chicago Outlet, which drained Lake Chicago southward in quite recent geologic history. The rock floor is but seven feet above low water of the present lake, though alluvial deposits are four feet higher, and only thirty feet above the Niagara outlet at Horse-shoe reef, opposite Buffalo. Prof. G. K. Gilbert, of the U. S. Geological Survey, has estimated that changes now going on will fully restore the ancient outlet in about 2,500 years.

For present purposes the Chicago Divide may be taken as that portion of the outlet from Lake Michigan to Lake Joliet, over which

work has been done by the Chicago Sanitary District, some five miles by the Chicago river, twenty-eight miles by the sanitary and ship canal and some eight miles down the steep slope from Lockport through Joliet, in all forty-one miles to the pool at an elevation of 76 feet below low water of Lake Michigan.

A well defined outlet valley and a developed stream bed extends from Lake Joliet to the Mississippi. The upper portion extends 54 miles to the head of the pool near Utica with a descent of 66 feet, reaching a level 142 feet below Lake Michigan. The river is for the most part 500 to 700 feet wide and descends by pools and rapids according to the resisting strata.

The lower Illinois is entirely alluvial and extends from Utica 227 miles to the Mississippi near Grafton with a declivity from pool level to normal low water at the mouth of 32 feet, or only 28 feet in the natural river. The values reported have varied two or three feet with the low water stage taken. The bed is generally from 600 to 900 feet wide, and some 700 square miles of bottoms are subject to overflow which is complicated by backwater from the Mississippi, the extreme high water of which is on a level with natural low water 30 miles below Utica. This extraordinarily low grade is unique among American rivers and is significant of the great volume of the ancient outlet, and the remnants of the old bed still exist in the deeps above Havana and the broad expanse above Peoria which have been much encroached upon in the historic period.

From the mouth of the Illinois to the Merchants bridge at St. Louis is 39 miles, with a descent of 21 feet, two-thirds of which is within the lower half of the distance. There seems to be a concentration of slope above St. Louis, due probably to the narrowing of the river for several miles opposite the city and the improvements below.

The Middle Mississippi extends from the mouth of the Missouri, 14 miles above the Merchants bridge, to Cairo. From the Merchants bridge to a point where the bluffs disappear between Thebes and Commerce and at the virtual head of the alluvial valley of the lower river, is a distance of 150 miles with a declivity of 78 feet; thence to Cairo point is a further distance of 39 miles with some 30 feet of fall. Low water at Cairo is approximately 303 feet below low water of Lake Michigan and 275.6 feet above mean tide of the Gulf of Mexico. The distance to the gulf is some 1,070 miles, and about 300 miles less to Red river.

The old Illinois and Michigan canal extends from the Chicago river 96 miles to La Salle, and the summit was cut down to lake level so as to draw its water supply from Lake Michigan. Locks and dams were constructed by the State in the lower Illinois at

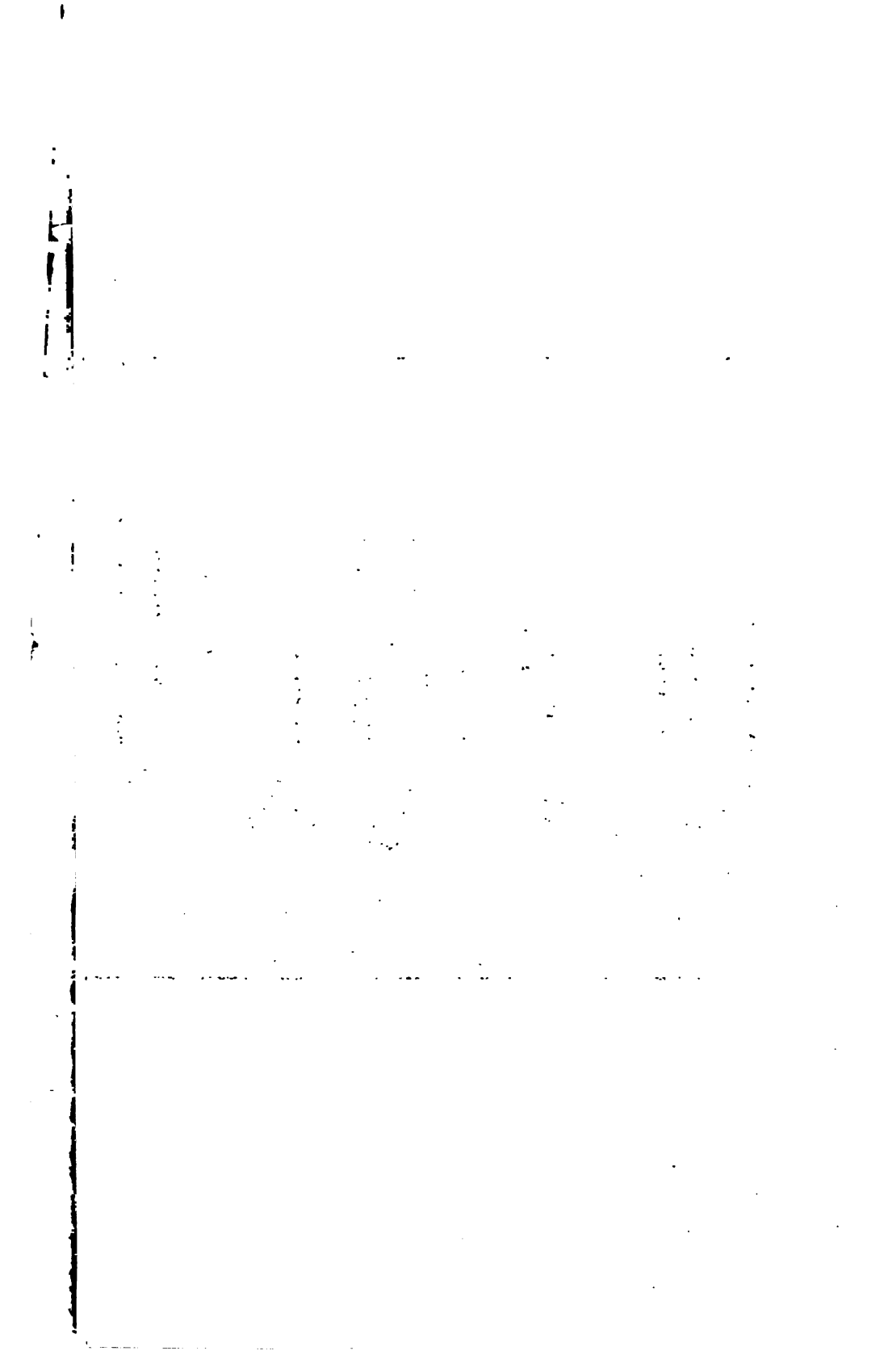
Henry and Copperas creek, and by the United States at La Grange and Kampsville, and these were designed for seven feet, but the pools have not been dredged. A depth of six feet was projected in the Mississippi at low water above St. Louis and eight feet below. Some dyke work has been done near Alton, St. Louis harbor improved, and regulation works more or less advanced for fifty miles below.

The accompanying profile from Lake Michigan to Cairo exhibits the elements of distance, grade and depth.

In 1889, the state of Illinois provided for a canal to carry 10,000 cubic feet per second across the Chicago divide, from Lake Michigan to the valley of the Illinois. The immediate cause of action was the sanitary necessities of the city of Chicago, and authority was granted after ample investigation had shown that the purpose could be served without detriment to any interest and in harmony with a sound and far-reaching public policy.

In consideration of the privileges to be enjoyed by the city of Chicago, under proper safeguards against abuse, the state of Illinois required that the canal should be built under a waterway specification, and that it should be a navigable stream in law and in fact. Appreciating that the old type of canal had become obsolete, and that the works projected and then partly executed for the lower Illinois were inadequate to future requirements, the public policy of the State was declared to be to procure all the depth practicable by the aid of a water supply from Lake Michigan, and that the navigable depth should not be less than fourteen feet; and the removal of the State dams was ordered, and the United States was requested to stop the work on existing plans and change to an open channel deepened by dredging. The State and its citizens have repeated these declarations on every suitable occasion, and it is not creditable to professional sense that they should have remained so long unheeded.

The reasons for this change had been well considered. A larger depth was not only possible but was essential to the maintenance of a channel over the low declivity of the Illinois. Banks were low, overflow was wide and inhabitation was fast bringing the spoils of the land; natural forces of deterioration were unhappily accentuated by the obstructing dams. What was then obvious to the discerning has since been demonstrated by two examinations and is generally accepted by the well informed. The remedy is a strong flow in a deeper channel, to be secured by removing dams, by dredging and by a water supply. This accorded with every riparian and



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sanitary interest, so every consideration crystallized in the one policy.

The agency created is the Sanitary District of Chicago, which has so far carried out the works authorized as to open the main channel for a part of the water contemplated by law. This channel carries some 24 feet below low lake level, and is 160 feet wide for nearly fifteen miles through rock, and 202 feet wide on bottom, and 300 feet at the water line, so far as completed in earth cutting, toward Lake Michigan. Some thirty-five million dollars have been already expended and the eventual completion will probably involve fifty millions.

Over the eight miles down the steep slope from the end of the canal at Lockport and through Joliet to Lake Joliet no cheap solution offers, and the boldest and most radical plan promises the best results, as measured by cost. The studies have proceeded on the theory of extending full canal depths to Lake Joliet in a prism ample for all floods so as not to disturb commercial use, the locks to be adequate for a fleet of six barges, each with a dead freight capacity of 2,000 tons, rafted with a towboat for river towing. This portion of the work has been estimated at eight million dollars, over a length of eight miles. The doing of this portion by means of prison labor, under the auspices of the State, has been discussed. A bill looking to that end passed the General Assembly of Illinois in 1895, but failed to receive executive approval.

From Lake Joliet to Utica is a simple slackwater proposition of 54 miles and a descent of 66 feet, which can be covered in three levels. The natural flood velocity over the declivities is considerable, and a liberal prism is required to reduce the same to proper limits, involving heavy work at localities. A study and estimate have been made for 16 feet, with miter sills at 20 feet, so as to permit future deepening; also, with the levels so arranged as to permit the flow line to be raised four feet, if ever demanded. The estimate is ten million dollars.

From Utica to the Mississippi is a plain proposition for cheap hydraulic dredging for the most part, for a channel of a bottom width of 300 feet and carrying 14 feet of water. Something less than seventy million yards are involved, with no allowance for assistance by the stream, and back channels, sloughs, marshes and adjacent banks furnish convenient places for deposit in most localities. The estimate has been taken at seven million dollars. A special dredging fleet developing the work progressively through a series of years would probably produce a more liberal channel for the estimate and so place the material as to assist in the reclamation of the bottoms.

The total is twenty-five million dollars from the end of the sani-

tary and ship canal at Lockport to the Mississippi near Grafton, a distance of 289 miles. This is only half of the liability devolved upon the Sanitary District of Chicago. Over the first eight miles the works must be completed as a whole at the outset. The remainder of the route only requires three locks and dams to be built to their final capacity at the outset, while the prism of the river may be progressively developed.

No detailed studies have been made over the 39 miles from the mouth of the Illinois to the Merchants bridge at St. Louis. The slope of the Mississippi is quite easy, about seven feet for the first twenty miles, while it is some fourteen feet over the following nineteen miles and complicated by the entrance of the Missouri. A dam at the end of the twenty miles and below Alton, raising low water perhaps ten feet, would conform to the easy slopes of the Illinois and make the extension of deep water to this point comparatively easy. Regulation works may lower the low water plane still further at St. Louis and such a dam will furnish a point of rest up stream. If the Missouri should unduly complicate the extension of works of regulation to the dam, as a last resort, it would still be feasible to carry deep water to St. Louis harbor by a short canal and by developing channels behind Chouteau and Cabaret islands. No estimate has been made of this section and other solutions may offer, but much may be left to the citizen of St. Louis when he realizes the probability of deep water within a few miles of his door.

A project of not less than fourteen feet between Chicago and St. Louis would be justified if no Mississippi river existed. These are the dominant foci of the great interior, and at and between them swings the east and west movement of a continent. The Mississippi, with fifteen thousand miles of navigable tributaries, subject to development with the growing resources of the great valley, is only a further argument in justification. But the assumption that the Mississippi is not now available for a through navigation of fourteen feet, is not warranted.

A study of the stages of water will show that this depth can be carried through for five to seven months of the average year, and the experience in old steamboat days, with such craft as the Grand Republic and Jim Howard, justifies this inference.* Barges that are stanch enough to traverse the great lakes and the Gulf of Mexico and Carribbean sea, will find ample reason for using this period which would not obtain in a purely local trade. An assured minimum of nine to ten feet is promised, which would prolong this

*"The stage from Cairo to the Gulf for two thirds of each year gives a navigable depth of over twelve feet."—Statement by John A. Ockerson, Member Mississippi River Commission.

period to seven to nine months, or to that of the eastward route, owing to closing by ice, and there would still be an available navigation for the remainder of the year. The upper Illinois may be closed by ice for sixty to seventy days, and in many years not at all. With the aid of ice boats, interruptions would be rare and of short duration.

To obtain twenty feet through the lower Illinois is simply a matter of water supply and dredging, and the greater depth and volume are simply further elements of insurance against deterioration. A large volume is as desirable on the low declivity of this stream as is low declivity for the large volume of the Mississippi. From Utica to Alton dam a channel of increased width would probably demand the removal of additional material of double the amount required for a channel of fourteen feet, and necessitate a water supply of 25,000 to 30,000 feet per second.

The structures have already been projected for the capacity, and the additional work for the enlarged prism between Utica and Lake Joliet would be a fraction of the total estimate for fourteen feet. The works between Lake Joliet and Lockport are already presumed to be adequate, and little additional would be required; but this situation may be improved by diverting the headwaters of the Desplaines to Lake Michigan.

Had the additional volume been provided for in the original construction of the Chicago canal it would have added little more than the additional excavation, or less than half the total liability of the Sanitary District of Chicago. To provide the additional volume will probably cost 60 or 70 per cent of that total.

The additional work from the Alton dam to St. Louis is simply a question of prism, not involving a large additional cost in the project for a separate channel over a part of the distance. The confluence of the Illinois, Upper Mississippi and Missouri all occur opposite an extensive bottom in a distance of twenty-five miles, and there are possibilities therein of changes in course, and a full study may develop a superior project.

The probable estimates are as follows: For a total of some eighty million dollars it is practicable to secure a navigable depth of fourteen feet between Lake Michigan and St. Louis, with a depth of twenty-four feet over the first forty-one miles, and this depth can be carried to Utica, ninety-five miles from Lake Michigan, at a moderate additional cost. Of this total the Sanitary District of Chicago is liable for fifty millions, and the State may be persuaded to donate prison labor for eight millions more. The remainder, twenty-two millions, is for a progressive development, half of which must be expended before a navigable route can be opened.

For an additional sum of 70 to 80 per cent, or about sixty million dollars, it is practicable to increase the navigable depth to twenty feet. After half the sum has been applied, the remainder will be a progressive development.

The project outlined by Mr. Seddon would logically carry the slack-water canal of his reservoir system through bottoms that come to the Mississippi in the bluff gap between Cape Girardeau and Gray's Point, some 140 miles below the Merchants bridge at St. Louis and about 50 miles above Cairo. The Mississippi passes through a rock gorge between Gray's Point and Commerce, leaving a detached bluff against the head of the alluvial valley on the west. The problem of the Middle Mississippi lies between this gorge and St. Louis and requires heroic treatment.

The dynamic solution demands increase of volume and lower declivity. By the construction of a dam at some point in the gorge and assuming a lower level at St. Louis due to regulation, half the total fall at low water may be taken out, while the works already discussed increase the volume by 50 per cent. Regulation under these changes in condition should produce most important effects.

That twenty feet will follow is not determined. The increased low water volume should increase bar depths almost in proportion. The slope at high stages is not so much affected, nevertheless the energy is reduced and especially during the moderate and most persistent stages, and this makes for economy of prism. The less variation in volume is of itself a force of amelioration. It is reasonable to expect large results as compared to what may be obtained under existing conditions.*

Time will be required for readjustment and to carry out works of regulation. Meantime hydraulic dredges can, as now, meet the needs of navigation at low water, and the flow can be increased by such a reservoir policy in the Upper Mississippi as local reasons should justify.

No estimate need be made except for the dam and locks and for the lands to be affected, which are not of great extent in this nar-

*The proposed dam would probably reduce high water declivity by 20 to 25 per cent, and the energy of the stream, as a whole, would probably reduce to some 70 per cent and require only that proportion of the former width for resistance. The general depth should be increased by some 40 per cent. Adding 50 per cent to the low water volume should increase bar depths in nearly direct ratio. It should be feasible, therefore, to obtain at least double the bar depths obtainable under existing conditions and as soon as the tendencies can be worked out.

row portion of the valley. The works of regulation are part of the present project.

Estimates for great and untried projects and dealing with such great forces have only a relative value. Nevertheless, the character of the problem between Chicago and St. Louis is such that what can be accomplished is as certain as about the great lakes and between the lakes and the seaboard, and experience is such that the estimates may be as safely relied upon. When all the data have been properly valued, the contingencies should not be large or the results uncertain. The only qualification pertains to the forty miles from the mouth of the Illinois to St. Louis, and it is possible to make a project which will eliminate uncertainty, but at considerable cost.

There is a determined and growing spirit for the development of the river southward from St. Louis, and little hesitation in Congress to supply the money. It is impossible to assume that, with the growing resources of the nation, this great artery shall be allowed to flow at will. Theories may be upset and effort prove fruitless, but only the egotist will set up his failures as the measure of future achievement and gauge all human thought by his own mental limitations. As long as water runs down hill and can serve a useful purpose, man will not cease in his efforts to utilize it. Then, from St. Louis to the Gulf of Mexico, it is only a question of some project which promises better results.

The distance from Chicago to St. Louis does not differ greatly from the distance from Lake Erie by the Erie canal to deep water of the Hudson river, and the investment of New York in her canal system is about the same as the cost of producing twenty feet between Chicago and St. Louis. Any depth, from ten to twenty feet, can be carried between these two cities for considerably less cost than across the state of New York by the Erie canal route. It would probably be less than by any route reaching the Hudson. The route would also have far greater capacity and quicker movement.

The physical conditions, as now understood, so far as they be practically available, do not seem to invite a present development much exceeding twenty feet in depth, to be obtained progressively, though this capacity must not be assumed to measure the possibilities of future achievement. The physical conditions by the St. Lawrence route and by the Champlain-Hudson branch, possibly by the Mohawk, do invite ocean navigation of thirty feet and upward. The two propositions, so far as involving the conservation, not dis-

sipation, of lake water, are mutually related, and in public policy the problem of lake control cannot be narrowed to an expedient of local navigation.

The immediate achievement of fourteen feet, based on a policy of progressive development to twenty, seems to best meet the physical, the commercial and the financial conditions. At the same time, limitations on the genius of those who come after are to be avoided.

Public policy contemplates the utmost development of resources. How far nations may grow is simply a question of how much there is, how far man may utilize it, and how wisely the benefits may be diffused and continued. What may come in a thousand years, or even in a century, is a matter of public policy which the present achievement cannot hope to discount, but clear ideas of public policy will decide alternatives, avoid projects that mar or blight the future, and design along the lines of a continuous development, so that evolution may proceed without loss to the final demand. The man who seeks to give direction to great movements without clear ideas of public policy and the moral force to abide by them, is but a parasite guided by his appetite.



THE SANITARY AND SHIP CANAL OF CHICAGO.

Lockport to Lake Michigan.

BY ISHAM RANDOLPH.

Expenditures for the improvement of the Mississippi River and its preservation as a navigable stream have been made by the United States government year by year for the last 20 years, until the aggregate of all the appropriations for that purpose reaches \$40,000,000, and today there is no greater depth for navigation than there was when the first appropriation was made. The thoughtless exclamation rises to the lips: "For what purpose was this waste?" but waste it has not been, since it has been only the payment for education in the school of experience; dear it may have been, but worth all it has cost. In October, 1897, as the representative of the Sanitary District of Chicago, I attended the Deep Water Ways Convention in Davenport, Iowa. The most striking address made before that convention was that of Judge Taylor, chairman of the Mississippi River Commission. He told of the work of that commission, of its sundry ventures and its manifold failures. From his point of view, the only success they had had in bank protection was with the willow mattress, and this mode of treatment was limited, first by the supply of material for making the mattresses, which would be exhausted in protecting a small fraction of the work to be done, and second, by its great cost, which was practically prohibitive. The only ray of hope which he saw for navigation, above the horizon of oft-repeated failure, lay in hydraulic dredges of the "Beta" type, a fleet of which, he thought, could successfully maintain navigation throughout the river at the low water stage. Since that time I have heard nothing to combat the gloomy views of the judge, and much to strengthen the idea that the wealth of the nation would not suffice to produce and maintain deep water in the pathway of the "Father of Waters."

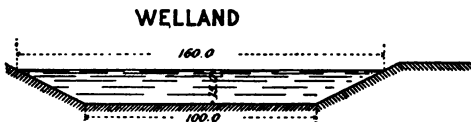
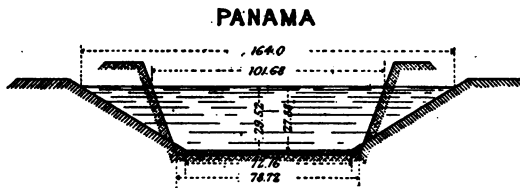
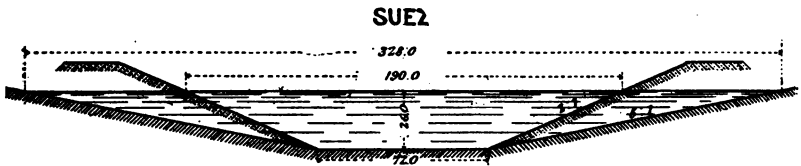
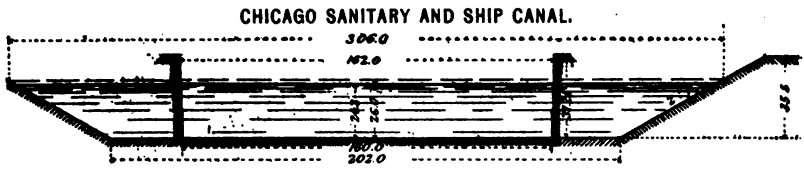
The recent perusal of the paper in which Mr. James A. Seddon gives the conclusions at which he has arrived after long years of patient observation—conclusions which he supports with arguments sustained by cited facts—reveals the first well considered project for maintaining an equilibrium between flood and low water stages in the great river, which has come under my observation.

To impound the surplus waters of flood periods in great storage reservoirs is certainly practicable, and it is no less so to feed the waters, so stored, back to the channel, and thus make good the deficiency in flow which obtains during the dry periods of the year. The estimate of cost placed upon this system of reservoirs, by Mr.

Seddon, is conservative and well within limits for which the work can be let to responsible firms of contractors. Mr. Seddon's paper is radical in its originality, and the courage of the author's convictions is sustained by the evidence which he arrays in their support. He breaks away from the beaten track, discards old traditions and opens the portals of hope to those who have at heart the development of our great mid-continent by cheap transportation from its center to the sea.

This presentation amounts to a demonstration that deep water can be secured and maintained from Cairo to the gulf; and if from Cairo to the gulf, why not from Cairo to Grafton and from Grafton to Lockport? The heaviest link in the chain from the Great Lakes to the Mississippi has been forged by the Sanitary District of Chicago. A single municipality has cut through the great divide. Thirty million cubic yards of glacial drift is piled high upon the prairies and 13,000,000 cubic yards of shattered rock stretch down through the Desplaines valley, and at the bases of these newly made mountains flows a river whose source is the Great Lakes. This river offers flotation to the largest craft which our lake ship builders have ever launched, and it is today the largest artificial channel in existence. For this river Chicago has paid \$33,000,000.00 and she is spending millions more to make the Chicago river a fitting entrance to its revolutionary extension. Under the auspices of the trustees of the Sanitary District she is widening the river to 200 feet, deepening it to 26 feet and removing all center pier bridges, and substituting therefor bascule bridges, the advantages of which to navigation are self evident. All of this Chicago is doing, and she stands ready to give all these results to the United States government, and in return she asks only that what she has so grandly inaugurated this government will carry to completion in the interest of all the people of the great middle west. It is my conviction that a deep waterway across the State of Illinois would be worth all it could possibly cost, within the limits of the most liberal estimates which have ever been placed upon it, even if there were no Mississippi to receive its effluent waters, and no hope of ever floating a craft beyond the line which limits the sovereignty of the commonwealth. To the State it would be worth the outlay, even were the last cent of the cost drawn from its own resources; worth it in commerce which would be born of opportunity; worth it in lands reclaimed; worth it as a minimizer of freight rates, because of the competition which would then exist between railroads and the cheapest mode of transportation known to commerce.

But this channel which is to be, and I say it with the emphasis of a deep conviction, is not for the State of Illinois, but for all the



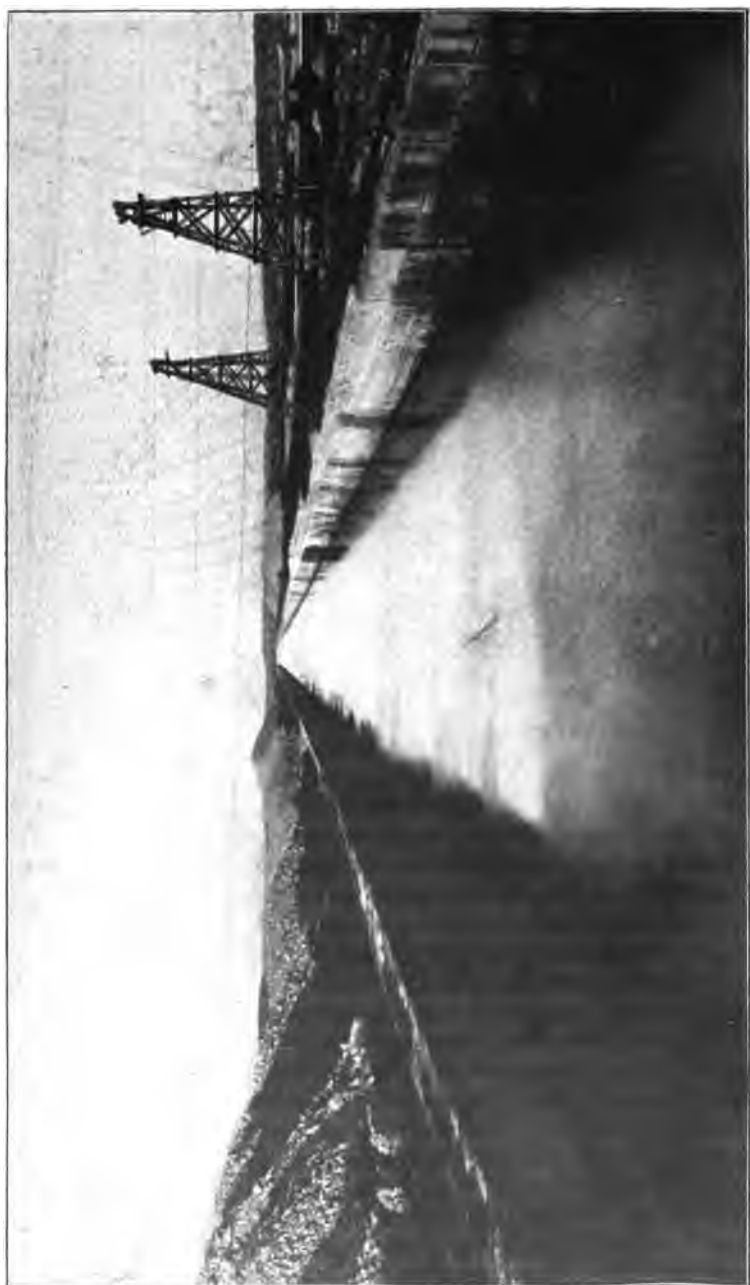
CROSS SECTIONS OF NOTED CHANNELS.

States of the Mississippi valley, and not for these alone, for every addition to the riches of a State is but a fresh contribution to the wealth of the nation; and no outlay which the nation can make has in it the promise of richer returns for the investment than has this project of a ~~deep waterway~~ from the lakes to the gulf. Our rulers stand ready to build an isthmian canal at a cost in excess of \$100,000,000.00 and the people give them godspeed in the undertaking. For less money this great interstate channel can be made a success, and its completion means infinitely more in substantial returns to the nation than does the opening of a highway through which ships may pass between the oceans which bound our coast lines, east and west. Our sanitary canal stands as a great forward movement in the arts of construction. There was a demand for economical methods, and American genius met those demands as American genius meets every demand upon it. New ways of doing things were inaugurated, new machines were devised, bold expedients were resorted to, failures were few, and the triumphs of that American genius were many, in witness whereof our man-made river is flowing today through its channel.

We've digged it through the prairie,
We've hewn it through the rock,
We've walled its sides with masonry,
'Twould brave the earthquake's shock.

And for economy of construction and successful achievement it stands without a parallel. The lessons it has taught shall not be in vain, and the channel which is to be, and which is to receive its waters, will be built better and at less cost to the nation because the men who will build it have the dearly bought experience contained in these lessons to guide them in their work.

Inasmuch as Mr. Seddon's paper and these discussions of it are likely to have wide circulation, it is proper to give a brief description of the sanitary and ship canal for the information of those who have not previously been informed as to this great work and its purposes. This work had its inception in the necessity of protecting Chicago's water supply, drawn from Lake Michigan, from contamination by the sewage of the city. The work was inaugurated under the general law for incorporating sanitary districts, enacted by the legislature of the State of Illinois, in 1889. The Sanitary District of Chicago comprises practically all of the city of Chicago north of 87th street, together with some forty-two square miles of Cook county west of the city limits directly benefited by the improvement. The entire cost of the work is borne by this District. The law provides for defraying the cost of the



FINISHED ROCK SECTION AT LEMONT, ILLINOIS.



BEAR TRAP DAM—UP STREAM SIDE.

work by direct taxation of the property within the district, and permits the sale of bonds to an amount equal to 5 per cent of the assessed valuation of the real estate in the district. The issue of bonds, however, is limited to \$15,000,000.

The sanitary district law requires that the supply of fresh water passing through the channel shall be 20,000 cubic feet per minute for each 100,000 inhabitants draining into it. The channel is constructed to meet these requirements of flow up to a maximum of 3,000,000 population. That is, a channel is provided which will pass 600,000 cubic feet per minute, flowing at the rate of 19-10 miles per hour.

The first division of this channel, extending from Robey street, where connection is made with the Chicago river, to Summit, a distance of 78-10 miles, is excavated through clay which can be easily and cheaply dredged, and this stretch has a cross-section permitting a flow of 300,000 cubic feet per minute at the rate of $1\frac{1}{4}$ miles per hour, at a minimum depth of 22 feet.

The main channel, extending from Robey street to Lockport, is 28.05 miles long. Its three natural divisions have the following dimensions:

Robey street to Summit—78-10 miles in clay, 110 feet wide on bottom; side slopes two feet horizontal to one foot vertical.

Summit to Willow Springs—53-10 miles through glacial drift, 202 feet wide at bottom; side slopes two feet horizontal to one foot vertical.

Willow Springs to Lockport—1495-100 miles through rock cutting (average depth of thorough cut in rock for about seven miles is about 33 feet). The rock channel is excavated 160 feet wide on the bottom; the sides are vertical, with two offsets of six inches each on each side, making the top width 162 feet.

The grade in earth is $1\frac{5}{8}$ inches to the mile and in rock $3\frac{1}{4}$ inches per mile. At Lockport the channel discharges into the Desplaines river through controlling works, consisting of seven stoney gates each having an opening of 32 feet, and over a bear trap dam 160 feet long. By means of these devices absolute regulation of the discharge is maintained. The flow can be shut off entirely, or the maximum discharge be made at will.

I submit a series of cross sections of noted channels of the world, also three photographic views of the Chicago Sanitary and Ship Canal.

This work has been carried on by a board of trustees consisting of nine men elected by the voters in the District. This board is vested with ample power to levy taxes, sell bonds, adopt plans, make contracts and do all things necessary to the carrying out of this stupendous work. The term of office is five years. The first



BEAR TRAP DAM—DOWN STREAM SIDE.

board was elected in November, 1889. The names of trustees who have been in office are as follows:

John J. Altpeter.	Elected Dec. 12, 1889,	served to Dec. 2, 1895.
Arnold P. Gilmore.	" Dec. 12, 1889,	" Dec. 2, 1895.
Richard Prendergast.	" Dec. 12, 1889,	" Dec. 2, 1895.
William H. Russell.	" Dec. 12, 1889,	" Dec. 2, 1895.
Frank Wenter.	" Dec. 12, 1889,	" Dec. 2, 1895.
Christoph Hotz.	" Dec. 12, 1889,	resigned Jan. 16, 1892.
John A. King.	" Dec. 12, 1889,	" July 22, 1891.
Murry Nelson.	" Dec. 12, 1889,	" June 19, 1891.
Henry J. Willing.	" Dec. 12, 1889,	" Sept. 23, 1891.
William Boldenweck.	Elected to fill vacancy	Nvo. 3, 1891.
Lyman E. Cooley.	" " "	Nov. 3, 1891.
Bernard A. Eckhart.	" " "	Nov. 3, 1891.
Thomas Kelly.	" " "	Nov. 8, 1892.
William Boldenweck.	Re-elected Nov. 5,	1895.
Joseph C. Braden.	Elected Nov. 5,	1895.
Zina R. Carter.	Elected Nov. 5,	1895.
Bernard A. Eckhart.	Re-elected Nov. 5,	1895.
Alexander J. Jones.	Elected Nov. 5,	1895.
Thomas Kelly.	Re-elected Nov. 5,	1895.
James P. Mallette.	Elected Nov. 5,	1895.
Thomas A. Smyth.	Elected Nov. 5,	1895.
Frank Wenter.	Re-elected Nov. 5,	1895.

The present board is composed as follows:

William Boldenweck, 1376 N. Clark street.
 Joseph C. Braden, 159 La Salle street.
 Zina R. Carter, 225 W. 16th street.
 Bernard A. Eckhart, 377 Carroll avenue.
 Alexander J. Jones, 805 Security Building.
 Thomas Kelly, 1411 Unity Building.
 James P. Mallette, 309 Tacoma Building.
 Thomas A. Smyth, 803 Jackson boulevard.
 Frank Wenter, 475 Ashland boulevard.

The presidents of the board have been:

Murry Nelson.	Elected Feb. 1, 1890,	served to Dec. 2, 1890
Rich. Prendergast.	" Dec. 2, 1890,	" to Dec. 8, 1891
Frank Wenter.	" Dec. 8, 1891,	" to Dec. 3, 1895
B. A. Eckhart.	" Dec. 3, 1895,	" to Dec. 8, 1896
Thomas Kelly.	" Dec. 8, 1896,	" to Dec. 7, 1897
Wm. Boldenweck.	" Dec. 7, 1897,	" to Dec. 7, 1900

DISCUSSIONS.

Mr. R. E. McMath—My occupation of late years has separated me from the consideration of these questions, but I have found the

time to read Mr. Seddon's paper, and have done so with much interest. He has followed out the line of reasoning that I started on many years ago, and has developed propositions which I foresaw were of sufficient practical importance to justify study.

The possibility of utilizing the St. Francis basin as a reservoir is certainly worthy of more than a mere discussion, and actual development of the possibilities by surveys should be made. For an application of the system of holding waters in reserve the St. Francis is admirably located, and probably well adapted by its profile and sections of its basin to that use. The water impounded could be delivered at the point where it is needed and the time would be subject to complete control.

As such a project would give a deep waterway over a large part of the line between the Great Lakes and the Gulf of Mexico the consideration of this waterway as a whole is a part of the question. For this reason, Mr. Cooley's discussion is a most important supplement to the paper. He outlines for the Illinois river, projects which have been clearly in view for some fifteen years; and for the intermediate link between the mouth of the Illinois and Cairo he gives plans that are at least engineering possibilities.

It is to be hoped, therefore, that, altogether, this paper may be a factor in bringing about a general review of the existing projects along this whole line—projects which, perhaps, were well enough some twenty-five years ago, when they were first formulated, but to follow them further is to ignore the experience gained in the last quarter of a century.

Mr. Thomas T. Johnston—Great credit is due Mr. Seddon for his clever presentation of the flow variations of the main rivers of the Mississippi valley, from which can be deduced at a glance many important conclusions as to the merits of reservoirs as a factor in modifying high water and low water river heights and volume of flow.

Evidently, headwater reservoirs, in order to modify materially the heights and flow of the Lower Mississippi, would have to be of such general and extensive application to all tributaries that their adaptability becomes impracticable. Mr. Seddon's discovery and determination of the physical fact that a system of reservoirs can be located in the St. Francis basin having a capacity sufficient to so materially modify high water conditions south of Cairo, and low water conditions south of Helena, opens the way for projecting other or auxiliary methods for the improvement of the Lower Mississippi, which have not hitherto been the subject, at least, of official mention, although, in the light of present facts, entirely worthy thereof.

It was about 1880, or a year or two earlier, that the govern-

ment entered upon the improvement of the Mississippi river below St. Louis with something like a fixed purpose. Confronted with a problem the limitations of which were essentially unknown the engineers, at first through the agency of the Corps of Engineers, U. S. A., and a little later the Mississippi River Commission, set about investigating the subject to some extent. Parties were organized and placed in the field in 1878-79 to measure various physical elements of the Mississippi and its main tributaries. Cross-section and its changes, flow of water with its velocities and directions of velocities, water surface elevations, sediment in suspension, topography slopes, and anything else that could be thought of were some of the subjects for measurement, in as many or more different ways as there were subjects, and as the ingenuity of the engineers could devise. Overflows attending floods, high and low water conditions and other physical phenomena were investigated. Experimental works of construction were undertaken, in order to learn their utility as river improvement devices. Various engineers were assigned to works at various points, essentially with carte blanche to execute such work as they thought best, and all in an experimental way. Having been identified with these earlier studies for some years the writer knows something of the bewildering mass of data accumulated in the course of several years, and can testify to the seemingly hopeless task of correlating its elements in a way to arrive at tangible information in a form useful for practical application.

It fell to the writer's lot to determine the physical dimensions of the Chicago drainage canal, and its collateral works known as the diversion of the Des Plaines river, the improvement of the Des Plaines river through Joliet, the improvement of the Chicago river for a capacity of 300,000 cubic feet per minute, etc., etc., after some seven years' continuous study of the physical data collected for the Mississippi river improvement, and it has been his privilege to follow this work to its successful conclusion and demonstration of the correctness of the calculated elements. The hydrology and physical characteristics of the region affecting the designs involved in the drainage canal were investigated and studied in manner and form corresponding to the afore-described investigations and studies for the Mississippi. Nothing could be more striking than the distinctive difference between the two undertakings, viz: In the case of the drainage canal the data was within such limits that it could be, and was, correlated in a manner to lead to tangible and definite results. Width, depth, grade, stability of construction, satisfactory and definite results, assurance of permanency and utility of the work and the wisdom of the expenditure were things all pre-determined before the work was undertaken, and the engineers proceeded with full confidence in themselves and in the results. In

the case of the Mississippi, while much has been learned, still the engineers have not been able, after twenty years of investigation and study and experimentation, to agree among themselves or with others upon any plan of works the results to follow from which can be confidently anticipated. The engineers have done the best that could be done under the circumstances, but the nature of their problem has been so stupendous and unusual that the failure as yet of a definite solution is not a matter of surprise.

The course of procedure adopted, largely forced upon the engineers before investigations and studies could be completed, has been, (a) to prevent overflow into the country adjoining the river by means of levees at or near its immediate banks; (b) the increase, to a very moderate extent, of the navigable depth at a few of the most shallow places by means of dikes, bank revetments and training works; (c) to prevent bank erosion at certain points with sundry purposes in view; (d) and, latterly, to erode annually, by means of hydraulic dredges, temporary channels at the most shallow points along the river. Protection from floods, and a possible navigable depth of ten feet at low water, seem to be the real aims, although a theory has been advanced that by confining the flood waters to the river channel and holding the river to a fixed location the tendency will be to lower the plane of the river and, possibly, in a general way to equalize the depths along the river and thus increase the navigable low water depth.

The levee construction, (a), has proved to be more of a task than anticipated, as to height, cost of building and cost of maintenance, and many doubt the commercial merits of further endeavor to bring the work to a conclusion. Certainly, it would be highly desirable to substitute some other construction that would accomplish the end in a more satisfactory manner, especially if it would remove the ever present menace of crevassed levees which must have existence if the existing project be carried to a conclusion. The endeavor to improve the navigable depth, (b), at a few stated localities has proved to be expensive tentative work, doubtful as to commercial advantage, and essentially impracticable in any reasonable length of time and at any reasonable expense if made generally applicable to all shallow places. The protection of banks, (c), from erosion is confessedly impracticable at any reasonable expense and in any reasonable time. The annual erosion of shallow places, (d), in the absence of anything better, is the most promising in commercial utility of any of the elements of the policy of the past. The depth to be obtained is small, however, and, as in the case of levees for flood protection, something better would be highly desirable.

Looked at from any point of view, the results of past efforts for

improving the Lower Mississippi are somewhat disappointing though far from discouraging if a broad view be taken of the difficulties that had to be met. It would be highly improper to indulge in criticisms of the course that has been pursued. It is, however, entirely proper to discuss any suggestion giving promise of a better project, especially in view of the tentative nature of all that has been done or that can fairly be anticipated, as indicated by the contrast between the Chicago drainage canal project and the Mississippi river project.

Mr. Seddon's suggestion involves a far more radical protection from flood waters, and a greatly more radical improvement of navigable depth than anything hitherto contemplated, and if it is feasible, with sufficiently definite results to be expected, at anything like the estimated cost, then it would be well worth while to throw away all that has been expended in the past, and take up the suggestion. This is true, even if the results to be hoped for as a consequence of the policy of the past were certain of realization at the estimated cost. No criticism of past methods is involved. It is simply a much better project recently evolved.

The suggestion will, however, bear close investigation before adoption. Only the general and interesting feature of feasibility of storage is announced. Many collateral considerations are involved.

Primarily, there is conflict with the fundamental theory upon which the existing project was based, viz.: "That the river being confined, in all its volume, to a single channel, the tendency will be to lower the plane of the river and generally equalize depths along the river to the end that low water depth will be increased." The converse has been stated, "that a division of the flow of the river will tend to cause the bed of the river to rise and further aggravate the difference in depth along the river." Much has been found in support of this converse by the instance of the division of the flow of the river at the mouth of Red river, where a large flow had existence into the Atchafalaya. However, as Mr. Seddon does not propose the diversion of any great volume, compared with the whole flow of the river, and since, in ordinary years, this flow from the main river will simply be at high flood crest, it is not probable that his idea constitutes any material infraction of the principle of the old theory. Some computations along this line would be interesting and instructive.

Perhaps the most difficult element to be encountered in carrying out this suggestion will be found in the entrainment of the water from the river in the vicinity of Cairo, not so much on account of the excavations and dams to be constructed, as on account of the form the slopes of the river will take during the period of entrain-

ment. Here, again, some figures would be instructive. It may be said, however, that unless the bed or plane of the river be changed, the order of slopes would be affected only during the period of entrainment. At times of extreme flood, when it is desired to lower flood level at Cairo by ten (10) feet, without a corresponding lowering of level at points upstream in the Ohio and Middle Mississippi, it would seem that there would be a heavy concentration of slope immediately above the junction of the two rivers. The change of velocity of the water due to subtracting the upper ten feet of cross-section in the region in question, and running all the water through the smaller sections, would not be great, so that the resistance to flow at any section would not be very greatly increased. The necessary result would be the distribution of this ten feet of slope for a greater or less distance upstream—doubtless so far that its influence in an objectionable degree might be essentially nil.

Another difficulty will be met in conducting the operation of entrainment of water at Cairo in different years. The floods of some years do not reach any considerable height, as in 1879, in which instance, in order to fill the reservoirs, Mr. Seddon would have to place his sills lower than contemplated in his paper. This is not serious, however, for proper disposition, to meet these contingencies, in the design of entraining gates and dams can be made. Computations would be instructive here again.

Should Mr. Seddon's suggestion be given application, it may very properly be regarded as an auxiliary to the existing project. That is, work could be continued and maintained along present lines as nearly as practicable, in the light of a flood height at Cairo ten (10) feet lower than hitherto.

There cannot, of course, be any question about the feasibility of constructing the reservoirs as suggested, and letting the water out of them in proper form.

The estimates given, though rough and doubtless too low, nevertheless show that the cost of the work is entirely within satisfactory limits. Suppose the results anticipated could be secured at twice the cost, the investment is still meritorious. Looked at from a commercial standpoint, the scheme has one great merit, viz.: the generation making the expenditure will live to enjoy some of its benefits. Ten years would easily suffice for construction. Again, the successful completion of such a project would develop the adjacent country as to usefulness and value to an extent that would be more than equivalent to the acquisition of a Cuba, or the Philippine Islands—and there are many who believe that, like charity, expansion should begin at home.

Mr. C. H. Tutton - I have been forcibly impressed by Mr. Seddon's paper on employing the St. Francis basin as a site for impounding reservoirs, and since nothing can be said against reservoirs, where, as in this case, they are shown to be feasible, heartily concur with the most of his remarks, but particularly with that, that "every dollar the government has spent and is spending on the front levee line * * * is probably adding ten dollars to * * * the cost of a reservoir system here * * * when the educational flood at last comes that makes the necessity of this reservoir system fatally apparent."

The raising of high water on the Mississippi by the system of levee protection is but a reproduction of what has been observed and recorded in France and other countries. The Loire, for instance, whose low water width is from 1,000 to 1,600 feet and overflow width from 2,200 feet to nearly four miles, has been leveed since 1706. Along about this time, and for a century following, they were from 19 to 21 feet high in places; averaging 15 feet in 1759; but being overflowed by the flood of 1846, they were raised some 3 feet, which was again shown by the flood of 1856 to be from 8 to 12 feet too little. It is plain to be seen that this was no more than a natural consequence of reducing the overflow width by nearly two-thirds, as is done by the levees of today. (Lechalas, *Hydraulique Fluviale*, p. 180.) In the larger Mississippi we would expect a greater change, and Mr. Seddon's remarks confirm this view.

Individually, I would suggest the abandonment of the idea of using this St. Francis basin channel for slack water navigation, substituting therefor an application of the principles laid down by M. Fargue (*Ingenieur en Chef des Ponts et Chaussées*) and which has been so successfully applied to the Garonne (see "*Etude sur la largeur du lit moyenne de la Garonne*," *Annales des Ponts et Chaussées*, 1882; also Lechalas, *Hydraulique Fluviale*, pp. 372 et seq.; also Flämant's *Hydraulique*, pp. 311 et seq.), to the natural bed as controlled in its height by the proposed St. Francis reservoirs. I believe that this system could be applied so that an enormous amount of dredging could be entirely dispensed with, and that the annual saving in dredging alone would repay the outlay on the reservoir, if not the entire system. I am not so sanguine of the permanence of the slack water channel through the basin.

I understand Mr. Seddon to say (see page 276) that a portion of the lower end of the St. Francis basin is now closed by levees. If this be so, I predict that his "educational flood" is much nearer at hand than it is pleasant to anticipate.

The whole subject has been treated very ably by Mr. Seddon, and his suggestion, even neglecting the fancied improvement above

presented, is worthy of far more attention than it is likely to receive at the hands of our financeering representatives in Washington. He deserves the thanks of the entire country, and particularly those of the residents of the Mississippi Valley, for thus fearlessly sounding the note of warning.

CLOSURE BY MR. JAMES A. SEDDON.

It is very gratifying to the writer to find that the engineers with whom he began his studies of these rivers in the early eighties, so fully appreciate the importance of his conclusions in regard to the improvement of the Lower Mississippi. To Mr. Cooley, Mr. Johnston and Mr. McMath he owes the important fact that he started with comprehensive views. Building, then, on their foundations, he in no way wishes to claim an exclusive credit in his final results, but to fully share it with them and other earnest workers in this line whose observations and studies he has profited by.

Noting first, however, some special points raised in the discussion, the writer is not familiar with the conditions in the European rivers cited by Mr. Tutton. He has not been able to get hold of enough data to really study such rivers, if, indeed, the data has ever been taken. And as there is more than a life's work in the data of the Mississippi system, for years the writer has confined his studies simply to that field.

For a deep waterway from Helena up, however, the necessity for a slack water system through the St. Francis reservoirs is plain. Below Helena the low water flow, with the St. Francis reservoirs, will be some 300 thousand cubic feet per second, while from Cairo to Helena it will be but 100 thousand, and with the original slope unchanged in this reach of river it cannot be made a waterway of depth equal to that from Helena down, though the greatly reduced floods will not tear up its bed and scatter its channels to the same degree, and it will certainly be a better river than it is at present.

In regard to Mr. Cooley's view of headwater reservoirs as a wise public policy to be followed through generations, the writer does not materially differ from him; and, indeed, as far as systematically storing the flood waters in the arid regions is concerned, he thinks it should be commenced at once. But the improvement of the Lower Mississippi is in progress, and the writer is considering alternative projects. The next Congress will be called on for another four years' continued appropriation of some \$10,000,000, and the question of how this is to be expended is a pressing one.

Indeed, the writer wishes again to emphasize the immediate need of a revised project of the Lower Mississippi. Up to the St. Francis basin, all that the government has spent on levees can not be said to have been misspent; it has more than paid for itself in the protection that it has given the valley, and while some of the present levee heights will not be finally needed, they will be needed for a continued protection until the St. Francis reservoir system is completed.

But the case is different with what is now being expended on the front levee line of the St. Francis. Every addition to that, is raising the extreme flood level down the whole valley, and needlessly risking the protection that has been given it; threatening the lives and property of the many people there now behind these levees and below them, without any engineering justification whatever; while, as a business proposition, it is about the equivalent of draining a man's swamp for nothing and then buying it from him at its enhanced value to make a lake out of it.

Mr. Johnston's discussion brings out a number of interesting points: First, the original theory in favor of levees, that the increased flood volume would cut out the river and lower the levels of its flow. This has now been under close observation for some fifteen years, comparing the gauge and discharge data during the progress of the present levee system with the conditions preceding it. From these studies in general it may be stated that the increased flood volume does tend to materially lower the level of the given low water flow. But much higher flood stages accompany the restrained outflow, and if these are being lowered at all they are lowering very slowly, and promise little, if any, general relief in their final limits. This river bed, however, is markedly more plastic in its lower part than it is in its upper, and answers more readily to such flood changes, as in the case below Red River, noted by Mr. Johnston.

Altogether, however, the experience with the leveed river has been a disappointment to the friends of levees. Some comfort was taken at first from the fact that the low water level in cases was unquestionably lowered; but when this is recognized as a condition incident to a marked increase in the rate of erosion and the cost of maintaining a levee system on these caving banks, it is not encouraging. Indeed, in many respects, the experience with levees was more nearly outlined by Mr. McMath in 1884, in his paper,* "Levees, Their Relation to River Physics." And though his caution could hardly have been taken at that time without some plan that promised a flood protection to the valley, still his insight into the problem has been largely confirmed.

* See Journal of the Association of Engineering Societies, Vol, III, page 43.

Mr. Johnston also calls attention to the important question of the high water regimen above the outlet, caused by the withdrawal of a large flood excess at Cairo. He notes correctly that the plans of the writer will throw the 10 feet cut off the top of the flood at Cairo into the extreme high water slopes of the lower Ohio. There is more or less of this here in any case, as the flood from the Ohio meets a high or low stage in the Middle Mississippi. Similar conditions also have been fixed by the overflows below Cairo, and from point to point along the whole course of the lower Mississippi, and again reversed in the reaches subject to inflow.

In the lower river these alternations of extreme flood volume are probably serious, but their effects are much less marked in the reach of the Mississippi below Cairo, and in the more stable regimen of the Ohio there is every reason to think that they will be insignificant. The writer is quite sure, therefore, that, in fixing once for all this variation in the lower Ohio, he has put it in altogether the best place for it.

Mr. Johnston, however, is quite right in questioning the level of 30 feet on the Cairo gauge as the fixed crest of this outlet. The writer did not intend to give the 30 feet as a final value, but merely to indicate the character of the work to be done there—a revetted bank, with weirs back from the river, in no way interfering with its regimen, and, indeed, out of water to something above the mid stages. It, perhaps, would have been better if the writer had said between 25 and 30 feet; but as this level can only be fixed after the capacity of the reservoirs is determined, in noting it he simply stated the higher limit.

Finally, the writer would deprecate Mr. Johnston's assumption that his estimates are too low. True, unforeseen obstacles may be met with; but in such tentative estimates of great works it is not uncommon to exaggerate the difficulties. Also, as noted by Mr. Randolph, in the case of the Chicago drainage canal, they are on a scale that warrants the introduction of every economy in the cost of their construction. With the general character of this basin marked by the 14 days that it takes the flood waters to pass through it, there is little doubt in the writer's mind that it could be cross-ridged to hold a great storage capacity very cheaply. And starting with levees of moderate height, and bringing in hydraulic dredges to build on them, he can hardly think he has underestimated the cost of it. In this, also, he is glad to see that Mr. Randolph, with his wide experience in large works, confirms the writer's judgment of the matter.

So much for the special points raised in the discussion; but in addition to this, Mr. Cooley's contribution so greatly widens the scope of the writer's paper that it is now no longer simply a proj-

ect for the Lower Mississippi, but a part in a deep waterway extending from the Great Lakes to the Gulf of Mexico; and as such is a matter in which the whole interior of this country is interested.

It is altogether nothing less than a project to bring a seaboard to the center of all the grain and ore and coal and timber in the great valley lying between the Rockies and the Alleghenies, and the final measure of its utility is today probably beyond the range of the wildest imagination.

It is interesting to note in Mr. Cooley's project, from Utica to the mouth of the Illinois, the same element of necessity for a deep waterway that the writer finds in the case of the Lower Mississippi. It is only in this way that the low lying bottom lands down that valley can be reclaimed and protected. But this deep waterway here is to be made by drawing on the reservoir of the lakes for its low water flow and dredging a suitable channel to take it.

The character of this 227 miles of the Lower Illinois is unique among western rivers. It may, perhaps, be best noted in the contrast between the three rivers, the Missouri, the Upper Mississippi and the Illinois, which meet to form the Middle Mississippi; in these the low water flow of the Missouri is some 25 thousand cubic feet per second; of the Upper Mississippi more than 30, while that of the Illinois was less than 1; and yet the three rivers had about the same navigable depths at low waters.

It is in this river, with little more than a tenth of a foot fall to the mile, that the Chicago drainage canal now promises to turn down an additional flow of 10 thousand cubic feet per second, and here Mr. Cooley well points out that a deep waterway is simply a matter of cutting the channel once for all with hydraulic dredges and turning in a sufficient flow to maintain it, while such a deep channel in its turn will carry off the moderate floods of this river without any destructive overflows.

From Utica up to the drainage canal at Lockport the line is simply a plain slack water system of river improvement and can be given as great a depth as is wanted. It is, however, specially desirable that the full development of the whole route should not be marred by insufficient works in this division. To put in fixed locks and dams on this line that would have to be torn out and replaced by larger ones before they even came to their full service would be a serious mistake here.

Where, however, dredging the channels is all that is required, the work may be developed progressively. Thus, the present flow from the drainage canal will not maintain in the Lower Illinois more than about a 9 foot channel, and to get this will cost some

\$2,500,000 and take some four or five years' work with hydraulic dredges. By that time, however, the full flow from the drainage canal will be in sight, and cutting the channel some 5 or 6 feet deeper may be begun, giving in the course of some ten years about a 14 foot waterway there.

By that time, also, the St. Francis reservoir may be put in, with a complete flood and bank protection and deep water to Helena, and the Lower Mississippi will be a river improvement finished with the exception of some \$400,000 annually operating a dredging fleet in cutting the slack water channels from Helena to Commerce. All this, also, may be done with less than twice the present annual rate of appropriations for that river, or but little more than double the estimated yearly cost of maintaining its levee system when completed.

With the Lower Mississippi then practically off its hands, and a gulf navigation in sight to Commerce, the government is free to turn its attention to developing the rest of this route to its full capacity. To carry a 20 foot depth down the Lower Illinois will take something like a doubled flow of lake water down that valley, and conditions around Chicago will then be developed that will make this additional flow very desirable. This also involves an artificial control of lake outlets and levels, which is even now being considered.

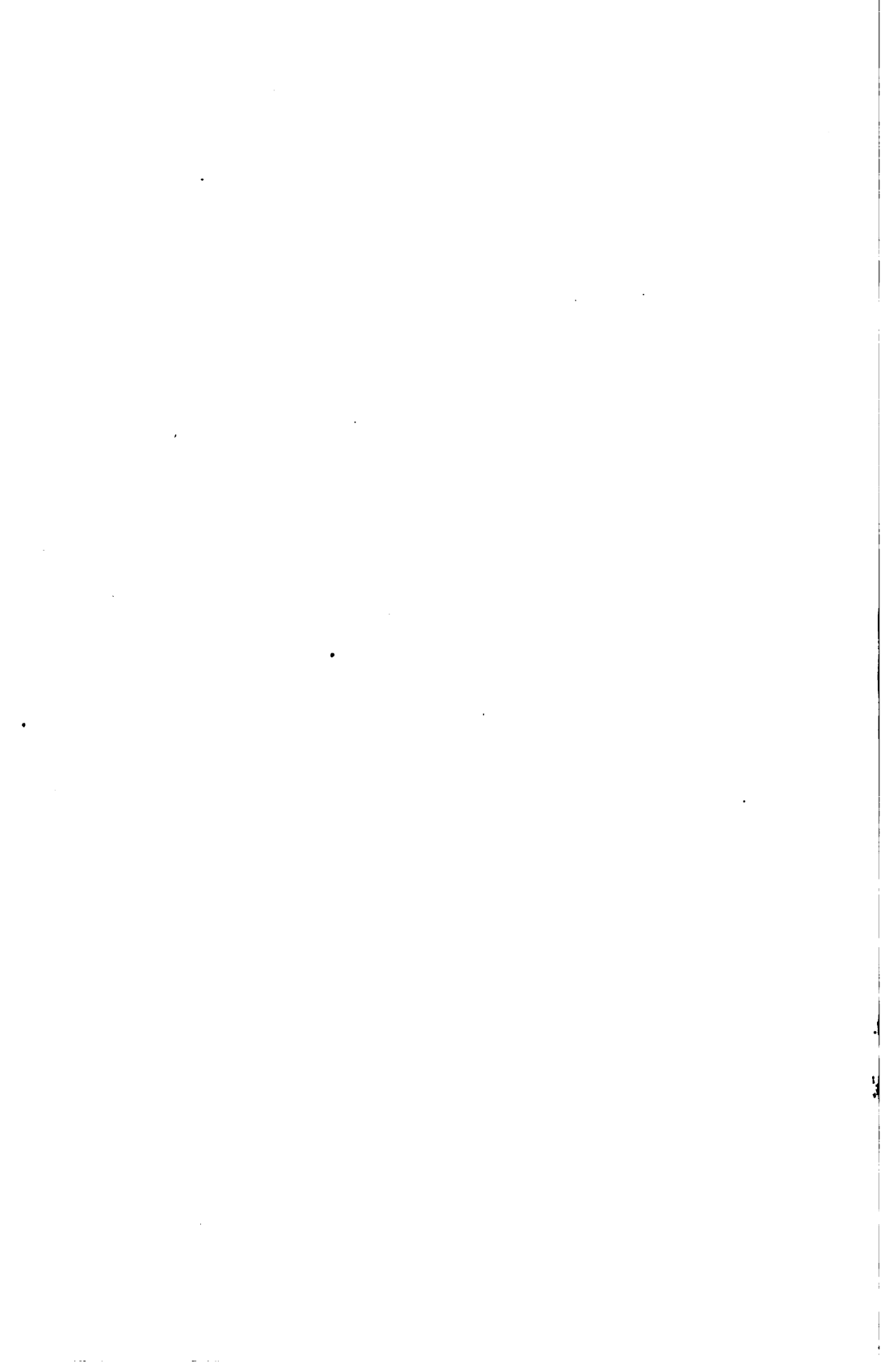
Here then, also, the problem of the Middle Mississippi may be taken up, and Mr. Cooley's plans for this are the first practical project that has been suggested for a really deep waterway over this route. Whether they are the best and the cheapest may be left for further study, and there is ample time to study them. For until the 20 foot waterway from the lakes to the Mississippi is in progress, from St. Louis down at least hydraulic dredges can keep open the 14 foot navigation through a large part of the season.

Altogether, then, the project for this deep waterway is a systematic development of the whole route to its fullest capacity, the works to cover a period of some twenty years, and built upon the costly experience of the last twenty. It is only necessary that it should be reviewed as a whole, and the annual appropriations expended in harmony with the whole project. On it, then, increased usefulness will follow moderate initial expenditures, and a growing commerce which does not now exist will rise to enrich the enterprise and reward the labor of the whole interior.

From the estimates given, the total cost of this waterway from Lake Michigan to the Gulf of Mexico, some 1,600 miles long, and nowhere less than 20 feet deep at all stages, may be taken as something between \$150,000,000 and \$200,000,000, or only some five times as much for this national enterprise as the city of Chicago assumed in cutting for sanitary purposes the first 33 miles of it.

As a further comparison, it may be noted also that this estimate is but little more than the cost of building the Nicaragua canal. The first brings a seaboard to all the products of the interior; the second opens a new line of exchange to products that have reached the coast. Both are desirable, but the first has the larger claim, even aside from the fact that the dollar spent by this country on its interior waterway is both to have the waterway and to keep the dollar. Certainly, then, as Mr. Johnston puts it, in the matter of waterways, at least, expansion should begin at home.





PERSONAL NOTES

The following personal statements are inserted for the purpose of illustrating the ability to be attached to the several contributions herein:

JAMES A. SEIDON, Assistant in the United St. Engineers on Waterways through Illinois Valley, Chicago, Ill. Mr. Seidon is exclusively engaged in engineering work in the analysis of data of the Mississippi River and its tributaries. He is the author of a number of papers and monographs on river physics and, notably, of a complete system of river hydraulics with special reference to Illinois rivers. (See Transactions of American Society of Civil Engineers.) He is recognized to be the best authority in regard to the technical relations of discharges in stage to those from

LYMAN R. COOLBY, Consulting Engineer, Chicago, Ill. Mr. Coolby was for five years upon the Missouri and Mississippi rivers. Early in the history he was chief civil engineer on the Missouri, the pioneer work in the modern system of river improvements. He presided the Sanitary Canal of Chicago from its inception; he held various positions under the city and state, and was the chief engineer of the enterprise and later a trustee and consulting engineer. Mr. Coolby gave the first firm in the solution of all the problems pertaining to the Chicago Sanitary Canal, its relation to water and sewer, and its sanitary and constructive features, and his work has been that of unquestioned and standard the highest authority. In 1896 he was employed by President Cleveland's committee of the International Commission to consider the project of a dam spanning from the Lake to the Atlantic, and with James H. Angell of Michigan, and John E. Russell of Massachusetts, made the report that gave the first substantial basis to the engineering world of that country.

ABRAHAM RANDOLPH, Chief Engineer Sanitary District, Chicago, Ill. Mr. Randolph has been chief engineer of the great canal for seven years, and throughout nearly the entire period of construction. He has also had a large experience in public work, gone to that of the Sanitary District. His position in all matters of construction and cost is fully recognized.

THOMAS P. JOHNSTON, Consulting Engineer, Urbana, Ill. Mr. Johnston was a pioneer worker in the history of data of the Mississippi river and tributaries taken up there was carried to a conclusion by Mr. Johnston. Mr. Johnston has been assistant engineer since the organization of the Sanitary District, and consulting engineer during the last two years. He has had extensive knowledge of the hydraulic problems involved from the river to the Gulf of Mexico.

JOHN W. McMASTRE, President Board of Public Improvements, St. Louis, Mo. Mr. McMaster was for twenty years identified with various river improvements, and was one of the earliest workers in hydraulic data. He was for six years on the improvement of the Illinois River, under General Wilson, and was a successive surveyor and auditor of that river, and he gradually had interest in regard to the channel of that stream and its capacity for improvement. Mr. McMaster is widely known for his work at the mouth of the Mississippi, and is the author of a number of reports and journals, among the last being a leading paper in the hydrological and geological.

C. H. TUTTON, C. E., Buffalo, N. Y. Mr. Tutton has been a close student of waterways and especially of the history of the improvement of Western rivers.

